CHAPTER 7

Irrigation Distribution

DESIGN OBJECTIVES FOR IRRIGATION DISTRIBUTION STRUCTURES

All irrigation systems face the task of distributing the water that arrives in the command area to the fields by some controlled means. The primary objective in designing water distribution structures is to provide a mechanism for controlled irrigation distribution, to accommodate the varying flow in the canal and distribute it as accurately as possible according to the planned allocation below that point. Another purpose of some, but not all, structures is to provide a mechanism for regulating the discharge to avoid breaching of lower-level canals and field bunds.

The task of designing a new irrigation system includes development of the irrigation plan. Among its most important elements are the rules concerning allocation of water to each irrigator or unit of land, definition of the service-area boundaries, rules about responsibilities and sanctions, and a mechanism for conflict resolution. The plan must fit the physical environment and also meet the sociocultural needs. In designing irrigation structures for water distribution, the water allocation rules are perhaps the most important element of the irrigation plan.

If the irrigators are not party to the exercise of preparing the irrigation plan or if the details of the plan are not negotiated to the irrigators' satisfaction before construction of the distribution infrastructure, the system will likely be underutilized or the irrigators will take matters into their own hands and make modifications in the structures.

Negotiating and agreeing to irrigation plans are even more important when an existing system is being improved. If it is a farmer-built system, for example, those who originally invested in building the system usually control the irrigation plan and manage the system. Even though they may be keen for assistance in making physical improvements in their system, if new distribution structures make it difficult to follow the allocation rules or monitor compliance it may bring disastrous results. This factor is illustrated in the case from Bali, Example 7.4, in this chapter.

IRRIGATION ALLOCATION

The allocation rules of the irrigation plan generally identify who will get water and where the water can be used. In some cases, they outline the quantity and timing of water delivery. Since the water supply is often variable, rules in the majority of systems specify how the available irrigation resource will be shared instead of specifying the quantity. Sometimes, the rules for allocating the irrigation supply will be different for each season in a year. The rules are often hierarchical in time of water delivery and geographical location (that is, there is often some system of priorities, according to which users' rights to water delivery are not uniform, but are arranged in some order so that certain users or groups have rights that are superior to those of others; such priority systems become particularly significant in seasons when water is most scarce). Agreement by the irrigators to the rules in their irrigation plan establishes their definition of equitable system operation. With hierarchical rules of water allocation, not all irrigators expect to receive equal water delivery.

The irrigation allocation rules define the decisions made about entitlement to water. The irrigation distribution activity is intended to deliver the water in compliance with the allocation rules. Irrigation planners, system managers and farmers all have some concern about the match between the water allocation and actual water distribution. Successful irrigation distribution structures will allow the water in the canal to be distributed according to the water allocation rules to the satisfaction of all parties concerned.

If the government's objective is famine aversion in a region by supplying irrigation for reliable crop production even during drought, it may decide to spread the irrigation resource as widely as it is feasible. This was the case when some of the large irrigation systems were planned in northern India. Water was allocated uniformly on the basis of land area but on a much larger area than the limited supply could fully irrigate. Since the quantity of water allocated was not enough for a water-intensive crop on each unit of land, it was up to the cultivator to decide how best to use his limited resource. The system managers set up a rigid schedule to deliver the water by timed rotation in accordance with planned allocation. The structures designed to deliver the water needed to be able to redirect the water in the watercourses according to the timed rotation.

In mountainous areas where farmers have grouped together to build their own system, they often establish the boundaries of the system on the basis of investment in the construction. In many cases, it is assumed that investment was roughly in proportion to each investor's landholding and the water is allocated by dividing it into shares proportional to landholding. The water distribution structures then must be able to control water delivery in accordance with each irrigator's share of the total supply.

Sometimes, investment in construction is more precisely determined and water shares allocated in proportion to the investment irrespective of the investor's landholding. These water shares may then became transferrable and new investors purchase water shares from those willing to sell. The water distribution structures in such systems must be able to accommodate changing shares of water and also provide facilities to monitor the water delivery. A structure that can accomplish this is described in Example 7.6.

There are many examples where it appears that the allocation of water was initiated on the basis of land area or fixed investment and then gradually adjusted to accommodate differences in infiltration rates or location relative to the main canal. Many factors including politics and power as well as consideration of equity have played a role in the local negotiations that have made modifications in water allocation possible. Frequently, totally different water allocation principles are applied for crops other than rice in the same system. In order to determine the appropriate mode of operation and select a design that can accomplish it, the water allocation rules must be understood or new ones prepared and negotiations with the irrigators completed before designing or modifying water distribution structures.

IRRIGATION DISTRIBUTION

Determining the irrigation plan and water allocation rules is fundamental in deciding on the type of irrigation structures to be built. However, consideration must also be given to the skills of the manager in manipulating the distribution. Implicit in this is knowledge of who the managers and operators of the distribution structures will be. Choice of a structure must also take account of the ability of both the system operator and the irrigators to adequately monitor the distribution and determine whether it is according to the allocation rules. Finally, the design selected must be able to meet the changing conditions of different seasons. Different levels of water availability relative to the water demand impose different constraints.

When water is abundant and each irrigator in a system can use as much as desired, little attention is paid to the water allocation rules or distribution practices. The primary concern for the distribution structures in such a case may be to control excess water which can cause damage to field channels and fields themselves. Gravity diversion systems in hilly environments with short conveyance canals often face such situations for short periods of time. One solution is to construct simple escape structures in or near the command area to divert excess water into a natural drain.

The other extreme is that of a limited water supply. In such situations, structures are usually necessary to redirect the water delivery alternatively among secondary canals. A gate with only fully open or closed settings is appropriate for this situation. Assuming that the allocation is related

Figure 7.0.1. Irrigators inspecting the water proportioning weir at the onset of the rice irrigation season in Palpa, Nepal.

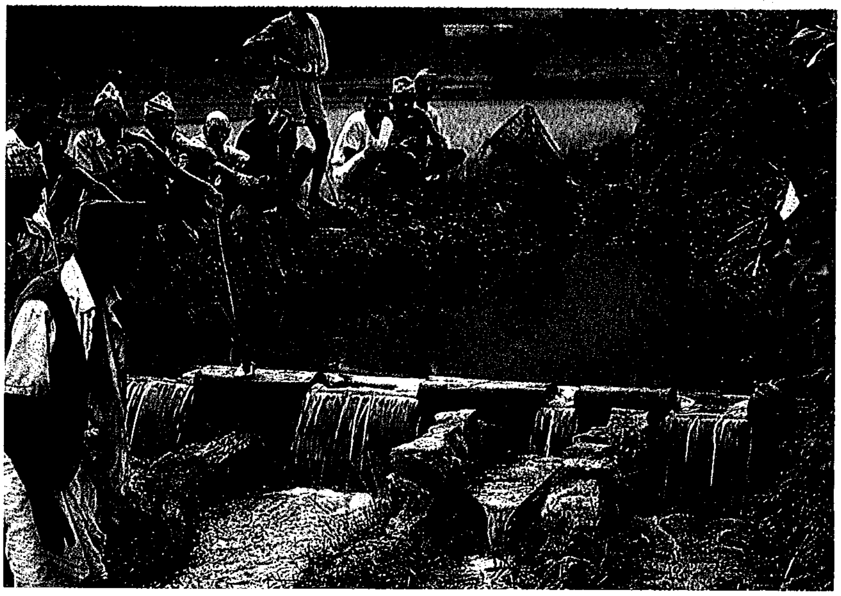

Photo by Robert Yoder.

The *saacho* (water proportioning weir) found in parts of Nepal illustrates this type of structure (Figure 7.0.1). A wooden beam with notches of equal depth is placed to block the canal so that all of the water flows through the notches into different secondary canals. The width of each notch corresponds to the shares of water to be delivered to each of the secondary canals. The sill of the weir is set high enough to form an upstream stilling pool and to keep downstream water conditions from affecting the discharge. In this case, the structure is the terminus point of the main canal and the secondary canals have been laid out so that each serves an area of the same size. All of these factors were considered by the farmers to reduce the error in dividing the water which is caused by entry contraction. Example 7.6 illustrates an engineered version of the proportional flow divider.

to the proportional share of the water available in the system rather than to a volumetric quantity, timing the delivery among channels and fields is an effective and common monitoring device.

Many irrigation systems, particularly those that are rice-based, try to find a middle level of water supply. If land is available, farmers allow expansion of the area irrigated to the extent that it allows them to conveniently irrigate their own fields but guard against expanding to the extent that it adds to their management cost or makes them risk water shortage during drought. Boundaries are usually set and water allocated to favor those that were the first to develop the irrigation system. As explained in Example 7.3, farmers in many countries have designed similar irrigation structures to distribute a middle-level water supply.

Figure 7.0.2. Water proportioning weir removed from operation during the dry season when water is more easily delivered by timed rotation among secondaries.

Photo by Robert Yoder.

Figure 7.0.3. Drop built ahead of a proportioning weir to create a pool and reduce the approach velocity, Parbat, Nepal.

Photo by Robert Yoder.

important part of the monitoring process that confirmed that water distribution would match the allocation rules. As mentioned in several examples in this chapter, the main reason that farmers prefer water proportioning weirs over adjustable gates under conditions of medium water availability is the ease and accuracy of monitoring water delivery.

When there is no storage in the system, water delivery varies according to the water available in the source. In periods when the supply is insufficient for continuous delivery to all fields, systems using proportional dividers often begin timed rotational delivery in the lower parts of the system. If supplies continue to diminish, the rotation moves up the system and eventually may replace continuous proportional division at the secondary-canal level.

Figure 7.0.2 shows the same water proportioning weir shown in Figure 7.0.1 as it appears in the dry season. Since the water available is only sufficient to irrigate one field at a time, the irrigators find it to be more convenient to remove the proportioning weir from operation and simply use stones and mud to divert the total flow among the appropriate secondary canals on a timed rotation basis. The purpose of the gathering of irrigators shown in Figure 7.0.1 was to reinstall and inspect the proportioning weir as they switched from the dry season to the rainy season operating mode; each irrigator receiving water through the weir was requested to attend and assist. Each had the opportunity to check that the sill of all notches was at the same level and measure to determine that the width of each was correct. This was an

Figure 7.0.4. Gated outlet from secondary canal to field channel without downstream control.

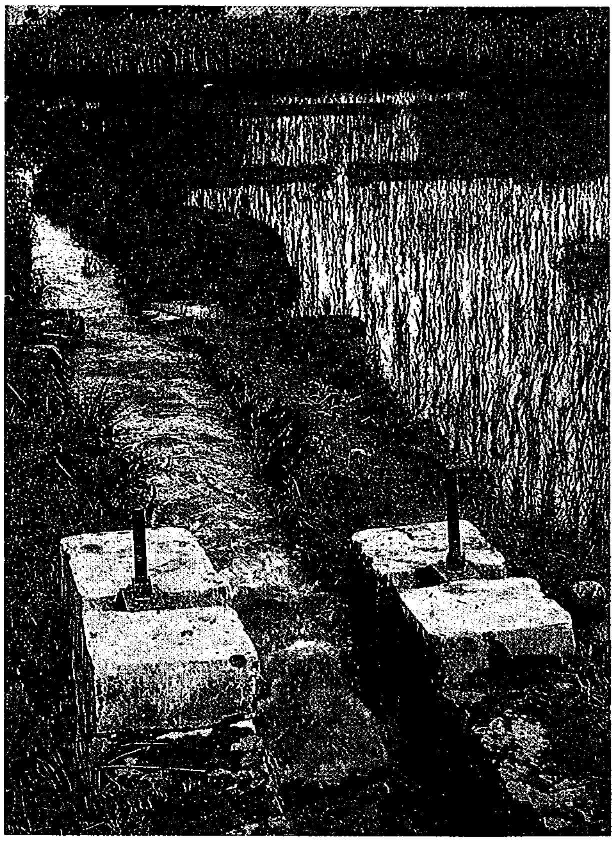

Photo by Robert Yoder.

While some farmer-built proportioning weirs have significant errors in dividing water due to poor design, farmers have shown ingenious ways of overcoming problems that they face. Figure 7.0.3 shows a drop constructed in a steep sloped main canal just upstream of a proportioning weir. The purpose was to create a pool to reduce the approach velocity for more accurate water division.

Dividing the flow from a large canal into small fractions was recognized as being inaccurate due to entry contractions. A solution the farmers in Bhutan devised was to construct as many equal-width openings as the denominator of the fraction being diverted to a secondary, and simply rejoin all but one immediately below the structure, i.e., if an eighth of the flow was to be diverted to the secondary canal, eight equal openings were made with seven joined after the structure and one diverted. They assumed that the same contraction losses would be present in each opening thus neutralizing the error. Using metal sheets to split the flow in proportional dividers as suggested in Example 7.6 helps overcome the limitation that farmers have faced when building proportioning weirs using stone and wood. The edge contractions cause less error and the structures can be made smaller occupying less land.

Figure 7.0.5. Farmer-built dry stone masonry drop structure in distribution canal in Gulmi, Nepal.

Photo by Robert Yoder.

Figure 7.0.6. Farmer-built drop structure using forest products in Nawal Parasi, Nepal.

Photo by Robert Yoder.

Figure 7.0.4 shows a gated outlet structure designed to distribute water from a secondary canal to field channels. Because the canal has a steep slope the water flowing through the structure has a high velocity and control of the water distribution is very poor. Even if properly constructed with a longer and wider segment upstream of the gates to reduce the approach velocity, it would be difficult to divide the water proportionally when discharge varies. If the structure is designed to distribute the water among field channels on a rotation basis, there should be an additional gate to block the flow in the channel directly through the structure. Farmers in many locations of the world have rejected gated distribution even when properly constructed, when their allocation rules called for proportional division of the water.

A number of examples in this section (Examples 7.5 and 7.7) mention the need for drop structures. When canals are operating on steep slopes, drop structures are an important consideration. When possible, they should be combined with outlet structures to save material. Figures 7.0.5 and 7.0.6 show drop structures built by farmers in a distribution canal to reduce erosion in the canal. Evidence from the figures indicates that structures built of stone are more effective than those built with the minimal use of wood.

EXAMPLES OF WATER DISTRIBUTION STRUCTURES

Example 7.1

Gated and Ungated Outlets for Allocating Irrigation Water in Nepal

Rishi Neupane[52]

Goal: *To provide outlets, for releasing water to 10 ha blocks, in such a way that water can be rotated among the canals in the dry season, while in the flood season high discharges can be admitted to the field so as to get benefit from the fertilizing value of their high silt content.*

To distribute water from the main canal to secondary canals or field channels in the irrigation systems that they have constructed, farmers often make a simple cut in the side of the canal for water to flow through. They regulate the flow from the main canal by inserting stones and mud from the canal bank into the cut. The continuously flowing stream through the cuts can widen the cross section and result in excess flow at the head reach and diminished flow at the tail end.

Since the discharge through the cut is difficult to estimate, a considerable volume of water may be wasted causing scarcity in the tail end of the command area. A simple brick or concrete, gated or ungated outlet, can be constructed in the canal to control the distribution of water to lower-level channels. This example describes brick masonry outlets used in a farmer-managed irrigation scheme in Rapti, Nawalpur, Nepal.

The Setting

The Rapti Nawalpur Irrigation Scheme was originally constructed by farmers. In 1985, a group of farmers from this scheme approached the government for assistance to improve the system. They wanted to add more area by reshaping the main canal and improving the diversion structure. The government provided them with technical and financial assistance. The water users' committee directed construction of the improvements in 1986 and remains fully responsible for operation and maintenance of the entire system.

The system being described is in the foothills of the Siwalik mountain range at an elevation of 500 m. The annual average rainfall is nearly 1,200 mm. The maximum temperature is 32 °C. Heavy rainfall occurs from mid-July through mid-October.

In this area, farmers grow rice during the monsoon season. Due to inadequate irrigation facilities in the past, some grew only rain-fed rice in a part of the command area during the monsoon season. For lack of irrigation, two-thirds of the total command area remained fallow during the winter season. Nepal's east-west all-weather highway crosses the command area making all parts of it easily accessible. Farmers can purchase agricultural inputs from the nearby service center.

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The water source is the Rapti River which has an abundant water supply during the monsoon and which overflows causing major floods. In the dry season, there is generally more than 1 m^3/s discharge. Part of this is from a hydroelectric plant just upstream of the diversion. The river has an intermediate slope at the diversion site. Flood water carries smaller boulders and gravel up to 200 m into the canal. The main canal is 4.5 km long and runs along the base of the mountain. In some places, the soil is very porous and minor landslides from the upper slopes cause the canal to breach periodically.

The command area starts almost from the beginning of the canal and is terraced. The size of landholding ranges from 0.5 to 1.5 ha. Farmers of the command area practice subsistence farming and there is little surplus production.

The Irrigation System

A group of farmers from the system applied to the Narayani Zone Farm Irrigation Office for assistance to improve the system. An overseer was sent to work with the farmers and collect preliminary data about the characteristics of the source, irrigable area, tentative route, the canal, porous areas, rocky areas and slide zones. The only constraints on water availability in the command area were found to be the low elevation of the riverbed and the length of the canal which needs extension. No issues concerning water rights were found.

The total construction cost was about US$ 24,000 and the irrigators paid 5 percent in cash and 20 percent in labor. After the improvements, the command area increased from 30 ha to 100 ha as estimated by landholding records.

A water utilization committee (WUC) of seven members was formed to operate and maintain the canal. The WUC is responsible for the management of conflicts and the mobilization of resources for maintenance. Each member of the system must provide labor or cash in proportion to his landholding. The amount collected each year depends on the extent of maintenance work. At the early 1991 exchange rate, about US$2.50 was collected per hectare.

There are a total of ten outlets from the main canal. Water is continuously available in the main canal even in the dry season. Individual farmers can apply water to their land as and when needed in the rainy season. During the dry season, the water is rotated along the distributors.

Design of the Outlet Structures

Information about the traditional water use system, flood water (with high silt content) used as fertilizer, and the relationship between the head reach and tail end of the command area was gathered during the investigation period. The use of 4.5 l/s of water per hectare for growing rice in the existing 30 ha of irrigated land was discussed with the farmers as was the field-channel layout.

To decide on the locations of the outlet structures, the technicians walked along the canal and discussed options with the farmers' construction committee. The following factors were considered: 1) each outlet should serve approximately 10 ha; 2) the level of discharge must be safe for the outlet; 3) existing highway culverts should be used; and 4) even the highest terrace should be irrigated.

A meeting was held with the farmers to finalize the selection of the types of structures. This meeting was attended by farmers from all parts of the canal. The technician facilitated the meeting and presented three alternatives for outlets and gates. The first was a controlled outlet with steel gate or adjustable planks, the second provided a medium level of control by using only wooden planks, and the third option was for uncontrolled outlets without gates.

Two major issues surfaced during the discussion. One related to the water supply needed by the tail-end farmers and the other to the need to be able to capture and spread flood water on the fields as fertilizer in the tail end of the command area. The technician proposed two alternatives for head-reach farmers to ensure a regular supply of water to the tail-end farmers. One alternative was to provide masonry outlets with steel gates at the head reach of the canal to regulate the flow as needed. The other alternative was to use a similar masonry outlet structure but with wooden planks instead of steel gates to regulate discharge. A locking arrangement for the planks makes it possible to control tampering.

The tail-end farmers proposed the second type for the head reach of the canal. For the tail end, they chose uncontrolled outlets without gates. This allowed them to have larger openings to fully use the flood water and other spring flows coming from the slope above the canal.

The area to be irrigated below each outlet, the gross water requirement (traditionally continued), and the upstream flow depth available at the outlet were the simple parameters used to design the outlet opening at the head reach.

Traditionally, the farmers use cuts in the bank about twice as large as necessary. The openings need to be large to accommodate the flood water. This larger size was adopted for the tail end of the system because this would satisfy the users who had determined the preferred size from many years of experience.

Example 7.2

Offtake and Footbridge in the Chirang District, Bhutan

Ian K Smout,[53] Robert J van Bentum[54] and Langa Dorji[55]

Goal: *To protect canal banks from damage by providing a combined outlet and drop structure, built of cement and masonry and including lining of adjacent canal banks. Also, to protect canal banks from damage by providing small concrete bridging slabs on the lines of existing footpaths.*

On small canals which have been built by the farmers, offtakes are normally made by cutting a hole in the earth bank through which water can flow to the fields. Clods of earth or pieces of wood are used to open and close the gap. This is simple but has the disadvantage of scouring the channel and weakening the bank, leading to problems of leakage, overtopping of the bank and, possibly, breaching the canal at this point. Similarly, farmers rarely build footbridges over small canals, as people and their animals can cross without much difficulty. However, this also tends to damage the bank, leading to the same problems.

To prevent the loss of water and risk of canal failure which result from these problems, offtakes and footbridges were constructed on the farmer-built canals in Bhutan which were being improved under the Chirang Hill Irrigation Project. The setting and description of the irrigation systems are given in Example 5.8. These were simple structures set on a short length of lined rectangular canal. The canal and structure walls were built of cement masonry, and the footbridge slab is concrete reinforced with mesh.

The positions of offtakes were selected with the agreement of the farmers during the survey and selection of works. In general, they replaced existing cuts in the bank, but care was needed to fit in with other structures, particularly pipelines. A footbridge was provided wherever a footpath crossed the canal.

The offtake and footbridge structure was one of a number of works designed for the improvement of existing farmer-built canals. The farmers requested that their canal should be improved, and participated in the selection of works and the construction, providing unskilled labor without pay. They remain responsible for operation and maintenance.

The Offtake and Footbridge Structures

Site investigation included walking the length of the existing canal with some of the farmers, identifying

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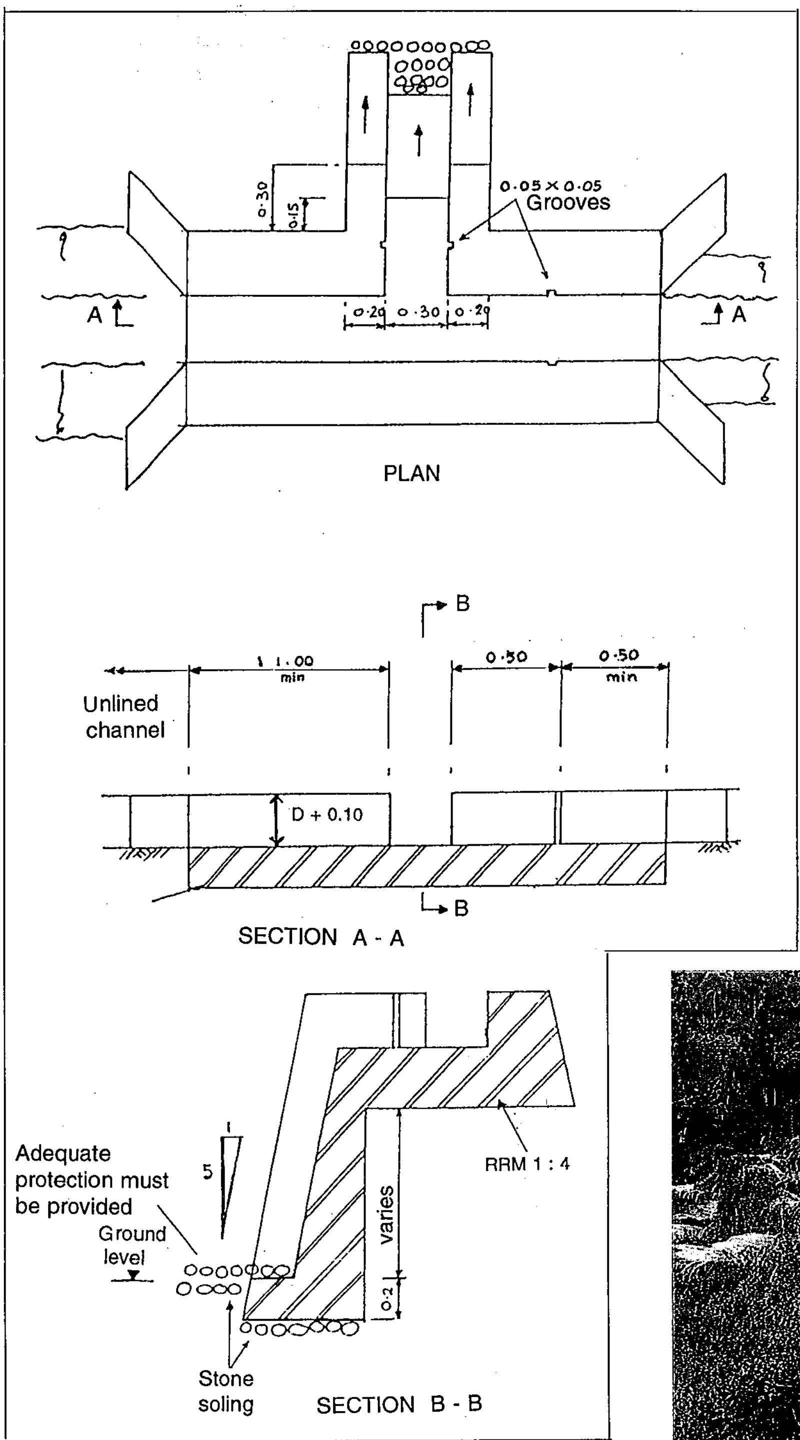
Figure 7.2.1. Plan of drop structure and offtake, Chirang Hill Irrigation Project, Bhutan.



the problem areas, agreeing on the works to be carried out, and collecting information. The information included the length of the canal and the command area, which were used to decide the design discharge of the canal corresponding to one of the four standard canal sizes: 26 l/s, 56 l/s, 104 l/s and 164 l/s. The locations of offtakes were agreed on with the farmers, usually at points where water was currently abstracted. Footbridges were located, with the agreement of farmers, at places of existing paths which crossed the canal.

The offtake structure is shown in Figures 7.2.1 and 7.2.2. It is a cement masonry structure with a standard 0.3 m wide opening, dropping onto large stones at ground level in the field. The stones must be arranged to provide adequate protection to prevent scour and erosion of the base of the structure. Grooves were provided in the opening and in the main channel downstream to assist the farmers in placing stones, earth, vegetation or timber

Figure 7.2.2. Drop structure and offtake, Chirang Hill Irrigation Project, Bhutan.

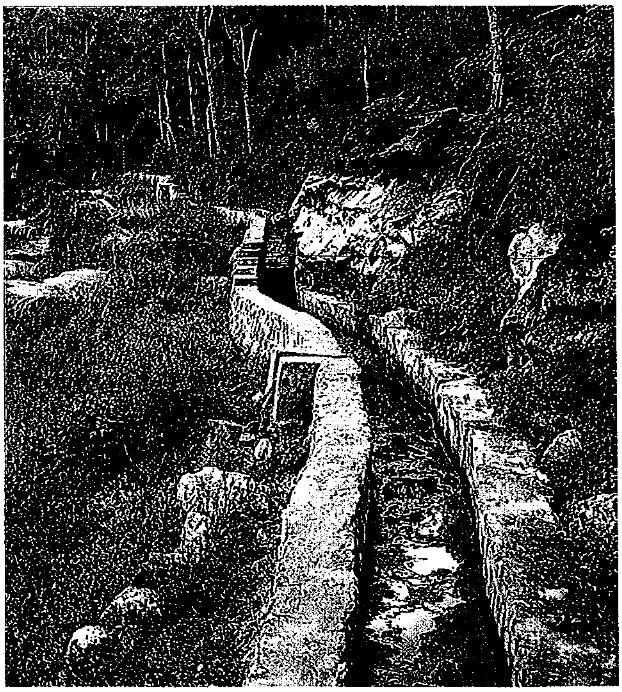
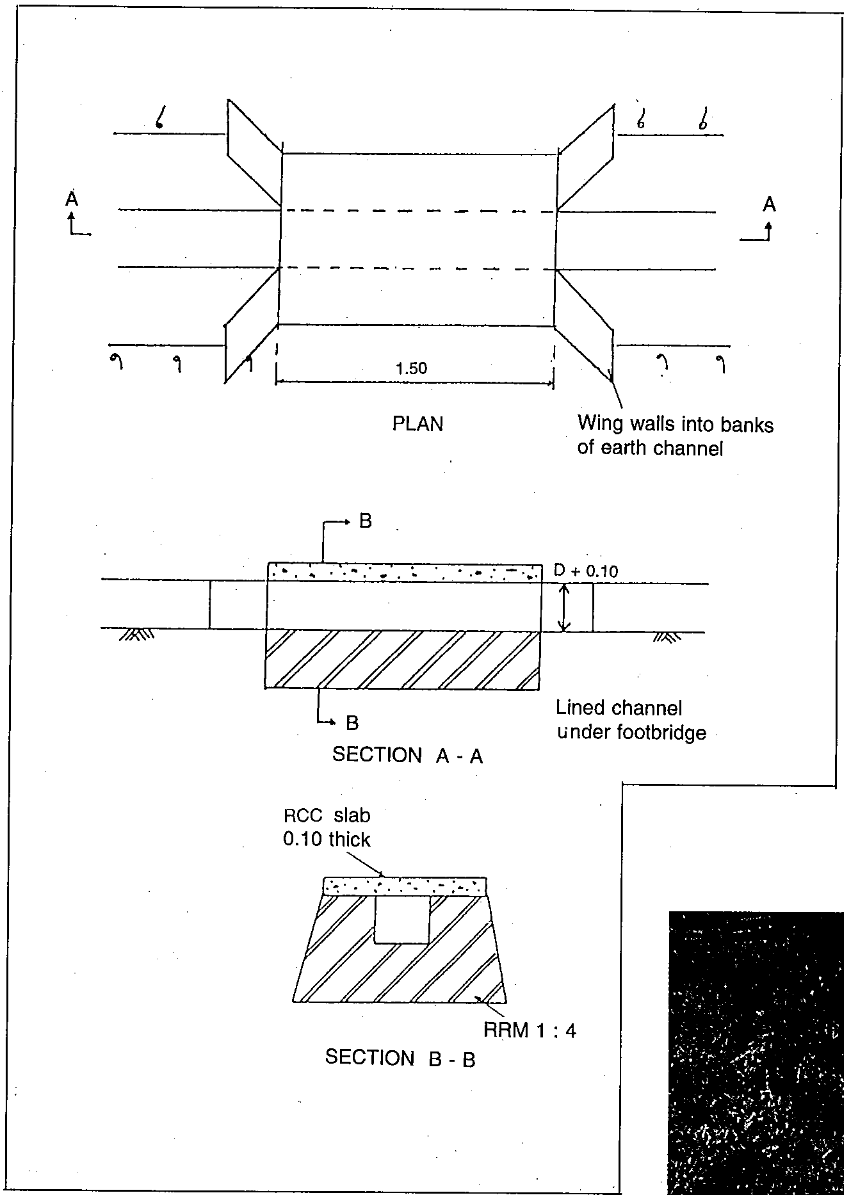


Photo by Ian Smout

Figure 7.2.3. Plan of footbridge, Chirang Hill Irrigation Project, Bhutan.



Notes: RRM 1:4 is random rubble masonry, with 1:4 cement mortar.
RCC is reinforced cement concrete.

to control the offtake. In earth channels, a minimum 1 m length of cement masonry lining was provided upstream and downstream of the offtake, and the ends of the lining were rounded into the earth banks.

The footbridge is shown in Figures 7.2.3 and 7.2.4. It comprised a 0.10 m thick concrete slab, reinforced with wire mesh, resting on a 1.5 m length of rectangular, lined channel. Where the adjoining rounded into the earth banks upstream and downstream. Initially, bamboo or timber was used instead of the reinforced concrete slab, but these had only a short life and the design was changed to concrete. This was generally preferred by the villagers.

Operation and maintenance are the responsibility of the farmers. Monitoring was to be undertaken by government staff and it was recommended that they check the stones which protect the base of the offtake. No problems were experienced with either structure. The farmers did not use wooden gates in the grooves in the outlet, but the grooves were still convenient for blocking the flow with mud and weed.

Figure 7.2.4. Footbridge, Chirang Hill Irrigation Project, Bhutan.

Photo by Ian Smout.

Example 7.3

Farmer-Designed Water Dividing Weirs in West Sumatra, Indonesia

John Ambler[56]

Goal: *To divide the flow of water equitably, at each successive canal junction within a small irrigation command of a few hectares. The farmers' conception of equity has evolved over a very long time, and incorporates the fact that lower fields receive, in the dry season, seepage flows from upper fields; therefore, the water divisions at the junctions are not proportional to areas served, but are arranged so as to supply more canal water to the upper fields.*

The Setting

The setting for this example is West Sumatra, Indonesia and details of its agriculture and physical environment are the same as those of Example 5.5. This example examines weirs placed at branches in the canal network to divide water into portions. The purpose of these proportioning weirs, here called *paraku*, is both to visibly record individual water rights and to physically divide the water according to these rights.

Water proportioning weirs have been documented in a wide variety of hilly environments, from arid subtropical to humid tropical. In Asia, they go by many names:

chaukhat	Gilgit, Pakistan
pantung	Pithoragarh, Uttar Pradesh, India
thelu	Kangra, Himachal Pradesh, India
saacho	Argali, Palpa, Nepal
gahak	Phalebas, Parbat, Nepal
gari	Pyuthan, Nepal
panidhara	Bhangbari, Nawalparasi, Nepal
khat bunda	Tanahu, Nepal
gah	Bhutan
karahankota	Central Sri Lanka
tae wai, tae nam, kiang nam	Chiang Mai, Thailand
sabang	Simelungun, North Sumatra, Indonesia
paraku	Lintau, West Sumatra, Indonesia
takuak	50 Kota and Baso, West Sumatra, Indonesia
kalimbatang	Baso, West Sumatra, Indonesia
penaro	Muara Enim and Lahat, South Sumatra, Indonesia
cowal	Sumedang, West Java, Indonesia
pemaroan, tembuku	Bali, Indonesia
tablon/padila	Ilocos Norte, Philippines

Topographical conditions in these areas are remarkably similar in many ways. But it should be noted that these structures are not found in all irrigation systems in areas of such topography. This example will focus on what are called *paraku* in Lintau, West Sumatra.

The climate of West Sumatra is humid tropical. Rainfall is bi-modally distributed, with a heavy rainy season occurring from September/October to January and a lesser rainy season from March to April/May. The driest months are June, July and August, with precipitation of about 75 mm per month. Rainfall in the catchment area of the rivers that feed the canals where the paraku are found is slightly higher, approximately 2,900 mm per year.

Rice is the only irrigated crop. Two crops of irrigated rice are grown each year. Yields range from 3.5 to 4.0 mt rough rice/ha per crop. The soil is suitable for wet-rice cultivation, but the heavy clay structure, which has developed through centuries of deposition of clay particles suspended in the irrigation water, is not suitable for many other crops.

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Farmers can choose what crops to grow, although both the soil and water and the government's policy of encouraging rice production for national rice self-sufficiency lead farmers to always choose rice.

The water sources for the systems under discussion here are Batang Ranah Batu and Batang Pigogah. These are very small streams, almost rivulets, that originate on the mid-slopes of Mt. Sago, a 2,200 m high dormant volcano that dominates the Tampo Valley in the subdistrict of Lintau Buo, West Sumatra.

The watershed of Batang Ranah Batu is only 16 km^2, while that of Batang Pigogah is 18 km^2. As a result, stream flow is highly dependent on local rainfall. Rainfall in the catchment area averages 2,900 mm per year. During the rainy season, these streams carry more water than is needed by the irrigation systems that draw water from them, while in the dry season, the water supply in the streams is so low that the headworks of each system can divert all the flow at that point into the main canal easily. Each canal is allowed to do this because even though the headworks of the systems are located an average of only 500 meters apart (300 m apart along Batang Ranah Batu), leakage from upper canals either returns to the stream or falls directly into the canal following a lower contour along the same slope. Seepage from the ravine banks into the stream is also picked up by lower headworks. No conflicts occur between different canal groups. Even during the driest months there is always some tiny amount of water flowing in the streams.

There are 10 canals that take off from Batang Ranah Batu, and 10 that divert water from Batang Pigogah. Canals in this area traverse slopes of the stream ravines that range in steepness from 20° up to 80° in some sections. Many sections of the Batang Ranah Batu ravine, and especially the Batang Pigogah ravine, are very steep. The soil structure of the slopes is very unstable. Only small patches of rock are exposed; most soils are volcanic inceptisols. The distance from the headworks to the first fields ranges from 500 m to 3 km. The ratio of canal length (from headworks to first fields), to irrigated area ranges from 65 m/ha to 1,000 m/ha.

Irrigated fields are leveled and bunded. Elevation differentials between terraces in the command area average about 30 cm. The average slope within the command areas is about 7 percent. Elevation of the systems discussed here is between 650 m and 750 m above sea level.

Some families own more than one parcel (0.25 ha) of land, and sometimes they own parcels served by different canals. Average total ownership of irrigated rice lands in the valley as a whole is 0.62 ha per family, while those who actually work in the fields (owner-cultivators and sharecroppers) have access to an average of 0.46 ha.

Only high-yielding varieties (HYVs) of rice are grown, IR-36 being the most popular cultivar during 1985. Chemical fertilizers and pesticides are used. Farmers market the surplus, often preferring to sell most of their crop to private traders who bring their trucks right up to the fields, weather permitting. Improvement of roads to get close to these systems is a recent development. Until the introduction of the HYVs in this area in the early 1970s, farmers only got one crop of rice a year and were sometimes unable to meet their subsistence needs. They used to migrate seasonally to work in other areas as harvesters, but since the introduction of the HYVs they stay at home and produce a second crop of their own; sometimes they even hire labor from other areas.

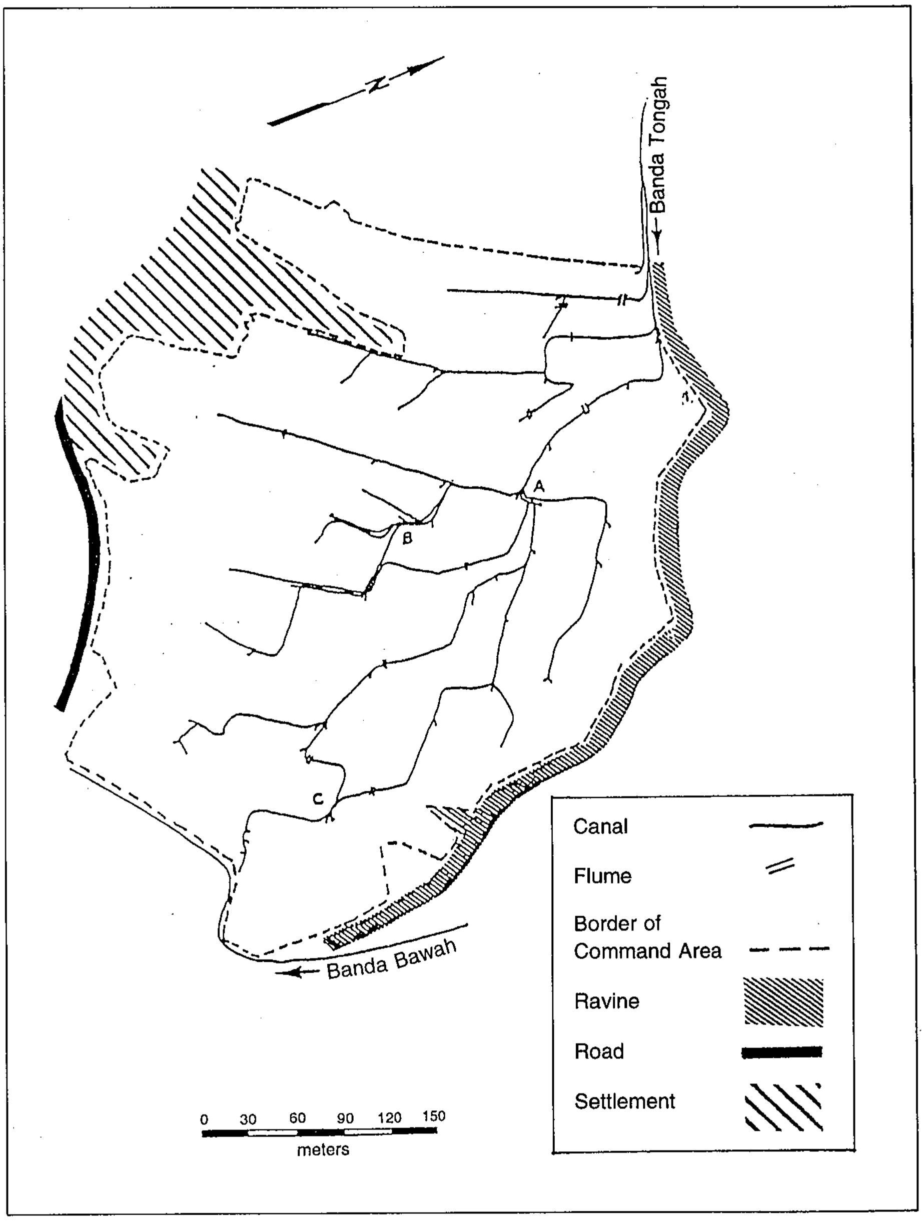
The Irrigation System

Command areas for the canals discussed here range from 2 ha to 12 ha. Within the command areas, farmers claim that water is distributed on the basis of equal water for equal land. Observations during 1985-86 indicate that water distribution closely follows this ideal. Perhaps this is not surprising because of the small commands, but because of the high conveyance losses in the unlined main canals that run along the steep ravine slopes, the water that actually gets to the command areas must still be carefully husbanded.

Farmers select one to three farmers from tail areas in each command to maintain the main canal during the irrigating season. These farmers (called *siak banda* in this role) are paid a set volume of rice, which is collected from each farmer in direct proportion to the land area owned by each. All these systems were originally constructed by the farmers without outside assistance and, with one exception that will not be discussed here, continue to be completely maintained and operated by them.

Conflict is rare, but when it does occur it is handled by clan elders. Conflict is usually related to nonpayment of the full quota of rice to the siak banda or tampering with the paraku. Siak banda are entitled to receive 100 kg of unhusked rice per hectare for their work during the season. Tampering is relatively rare according to informants, but the siak banda have complained that it has become harder and harder to collect the full payment due from the farmers, despite the amount of payment being fixed and the yields increasing. The delinquents are said to be those holding land but residing outside the village.

Figure 7.3.1. Layout of the water distribution system in the Banda Tongah Irrigation System.



The Proportioning Weir

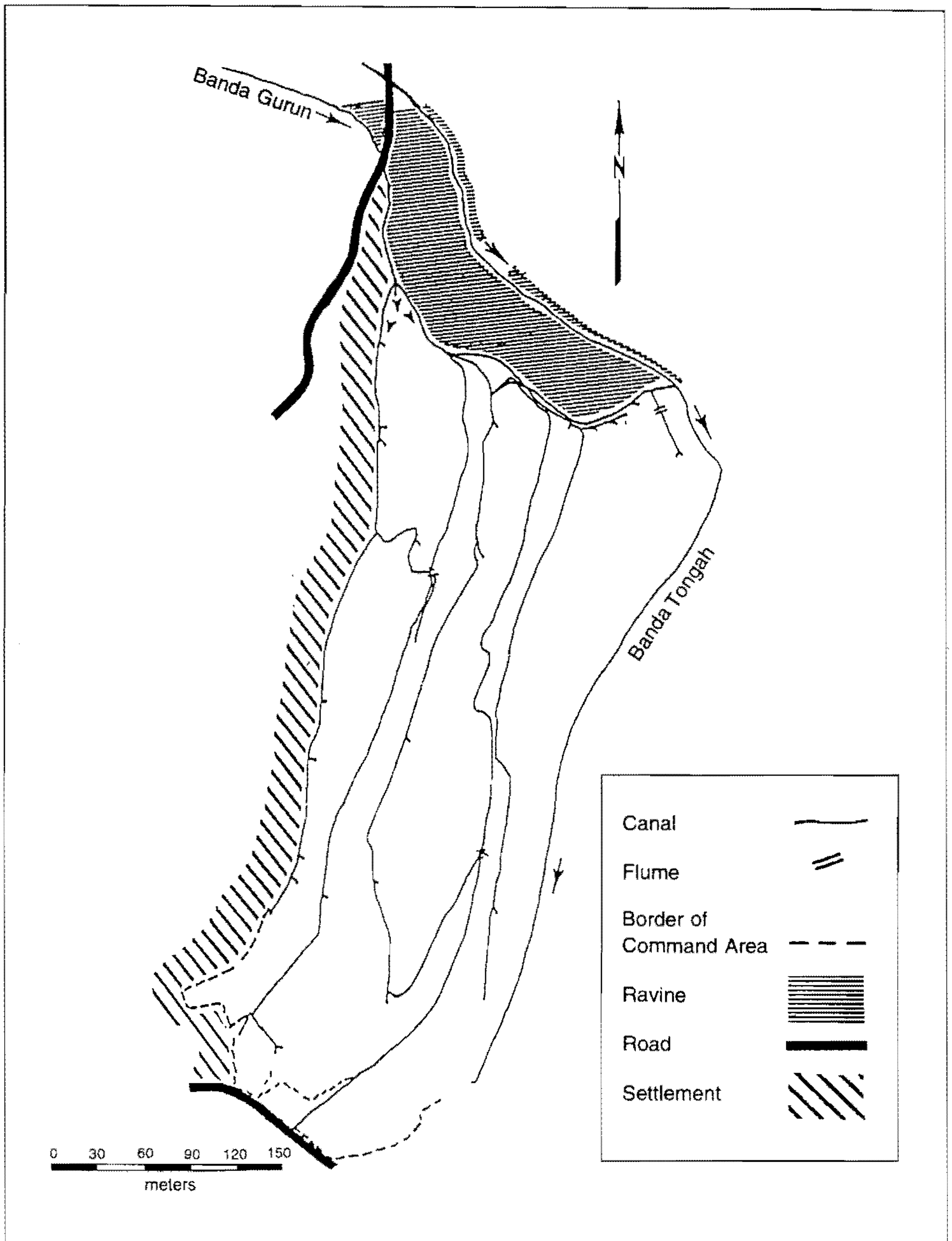
These systems are very old and the original design considerations that were incorporated into their construction are not known. No oral history on these aspects exists. Irrigation in the valley, in general, is at least 650 years old, although these particular systems are probably somewhat younger. The catchment area of the streams was originally almost certainly more densely forested. Now parts of the catchment, either leveled or unleveled fields, are under unirrigated cultivation. Erosion does not seem to be a major problem in most areas of the catchment. It is likely that the basic characteristics of the Batang Ranah Batu and Batang Pigogah were nearly the same at the time these systems were originally constructed.

Canal Layout

The layout of the canals is an important part of the water conveyance and distribution system. Two examples are given in Figures 7.3.1 and 7.3.2. Each parcel of land is served by an individual terminal canal. Each branch in the canal is equipped with a proportioning water division weir, a paraku. Ditch density in Banda Tongah (Figure 7.3.1) is 221 m/ha, while in Banda Gurun it is 343 m/ha. This indicates that farmers are willing to sacrifice scarce land for the greater water control obtained by using high ditch densities in combination with carefully calibrated water division structures.

The complicated dendritic system of canals, especially in Banda Tongah, suggests that the layout of the canal network evolved over time, possibly in response to fragmentation of holdings and/or changes in the boundaries of the command area or even changes in the water supply over time. Some ditches cross other ditches by means of bamboo flumes. It is unlikely that this elaborate network is identical to the original canal layout

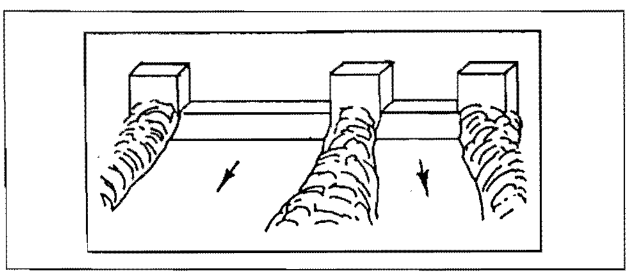
Figure 7.3.2. Layout of the water distribution system in the Banda Gurun Irrigation System.



Weir Design

A schematic of the proportioning weir is shown in Figure 7.3.3. Division of flows in these systems is accomplished by cutting two or more notches into a water-resistant hardwood log that is placed in the bed of the ditch perpendicular to the flow of water.

Figure 7.3.3. Typical proportioning water-division device.



The maximum discharge through these canals at the headworks is perhaps 25-35 l/s in the larger ones during the rainy season, and is as low as 10 l/s during the dry season. Volume of water delivered by the main canal at the point of entry into the command area ranges from approximately 0.5 to 1.5 l/s per hectare. These estimates of discharge are based on visual inspection, not on direct physical measurement. Frequent breaches in the main canal occur causing total disruption in water supply to the command. Breaches occur due to landslides from above and due to sloughing away of the canal into the ravine, while a constant problem is the activity of land crabs called *sirangkak* that burrow into the soft canal banks and cause leaks. The siak banda must be experienced to detect these leaks and plug the holes with mud.

The first paraku is usually placed close to the head of the command area. It divides the total flow in the canal for the first time. All lower paraku handle lesser amounts of water. Paraku work best under conditions in which there is free fall of water from the lower side of the structure.

The maximum length of the paraku observed in these systems is about 1.8 m. The largest paraku in any system is often the first paraku, but it need not necessarily be so. Terminal paraku, which may be serving two parcels of only 0.20-0.25 ha each divide very low flows and are very small (e.g., 30 cm in length).

Operation and Maintenance

The only routine maintenance needed is to make sure that the paraku is set firmly at the bottom of the canal and that no water is leaking around the sides or piping under the bottom, either intentionally or unintentionally. In systems in another valley, the author has seen paraku (called *takuak* by these farmers) with water running under the structure. On inquiry, farmers said that since it was the rainy season they did not need to be "dipakok" (battened down), but that when the water supply fell, they would be properly set in the ditches again. In the systems in Lintau, however, they are kept properly aligned year-round.

The flow of water over the notches in the paraku gradually wears the wood down. Every few years the paraku need to be replaced. New paraku of exactly the same dimensions are made and installed in the presence of clan elders and all farmers who directly or ultimately receive water via that paraku. The wood for the weirs is available from the nearby forest at no cost. The primary maintenance consideration for the farmers is the main canal that runs along the sides of the ravine before it reaches the command area.

Operation of the paraku is automatic. There are no moving parts. Except during land preparation when farmers may close off some of the paraku with mud to rotate water, or during weeding when water is not needed, irrigation is a continuous flow to all points of the network. Fluctuations in the discharge of the ditches is automatically translated by the paraku into proportional reductions or increases in the flow to all other downstream ditches. The tight-knit social relations between the farmers, small command area, and proximity of the settlements to the fields make monitoring of the weirs through the posting of guards unnecessary, even in times of very low flows. Water runs through the paraku all night long, but farmers are expected to stay away from their fields during nighttime, lest they come under suspicion of tampering with the paraku.

Irrigation water is measured in terms of *ameh*, the Minangkabau word for gold. These and other land/water share terms have derived from the money terms used in the l9th century in the area. It is not known if these terms also predate the coming of the Dutch in the mid-l9th Century. 1 *ameh* = 2 *kupang*; 1 *kupang* = 2 *tali*; 1 *tali* = 2 *bilah*. One ameh of water is supposedly enough to irrigate 20 *gantang* of land, or about 0.5 ha. Thus, command area can be expressed in terms of water units. Farmers speak of Banda Tongah as having a command area of 24 ameh, while that of Banda Gurun has a command of 18 ameh. The term gantang itself is a measure of volume, and refers to the amount of traditional variety of seed needed to plant a particular area of land (40 gantang for 1 ha). Farmers use modern varieties of seed now, but the term gantang is still used in the old way.

How closely do the water terms correspond to actual surveyed area? Farmers say that Banda Tongah is 24 ameh. The physically measured area is 11.9 ha. Banda Gurun is said to be 18 ameh, and its physically measured area is 8.5 ha. In other commands, too, the correspondence between the number of ameh and the physical area was very high. In 4 contiguous paraku systems, Banda Tongah being one of them, physically measured area equals 31.2 ha, while farmers say the total number of ameh is 64. Thus 1 ameh very nearly equals 0.5 ha.

How closely do the proportions cut into the paraku correspond with the area they serve? To find this, each individual's share of the total water should be correlated to his/her corresponding share of total land. Given that during the dry season of 1985, the time of scarce water, all fields in Banda Tongah had the same height of standing water, and there was no visible surface drainage from any field or overflow from a higher field to a lower one anywhere in the systems, it was expected that the correlation between share of water as measured from the paraku and share of land as measured by physical surveying would be very high. In fact, an adjusted R^2 of only 0.42 was found, indicating that only 42 percent of the total variance in water share could be accounted for by share of land.

Adding length of channel from the first paraku to the terminal paraku for each field raised the R^2 to 0.56. But the sign for this term in the regression equation was negative, meaning that head-end fields on average received proportionally more water through the ditch network than did tail-end fields. Yet the fact that all the fields had the same amount of water standing in the plots suggested that seepage from head-end fields to lower ones was taking place, and that this seepage had ultimately been factored into the proportioning of the notches in the paraku. The farmers claimed that except for one plot near the ravine, soil structure and percolation rates were uniform in the command area. The proportions have apparently been adjusted in accordance with the probable water supply during low stream flows. No farmer could remember the sizing of the paraku ever being adjusted, and they considered the present system a priceless inheritance from their forefathers.

During the rainy season, the condition of the main canal permitting, more water than is needed by the original command area is sometimes diverted and delivered. In the case of Banda Tongah, the extra water is taken out of the end of the uppermost field and conveyed across the road to another group of plots that were leveled and bunded around the turn of the century. These plots are entitled to receive this extra water—that is, they cannot be denied it—but if there is no extra water then they cannot demand that the original command give up any water to them. Thus, they clearly have secondary water rights. They are also not required to contribute anything to the maintenance of the main canal. In fact, they are specifically prohibited from doing so, because participating in that form of investment could lead them to claim primary rights to water, during the dry season as well as at other times of the year.

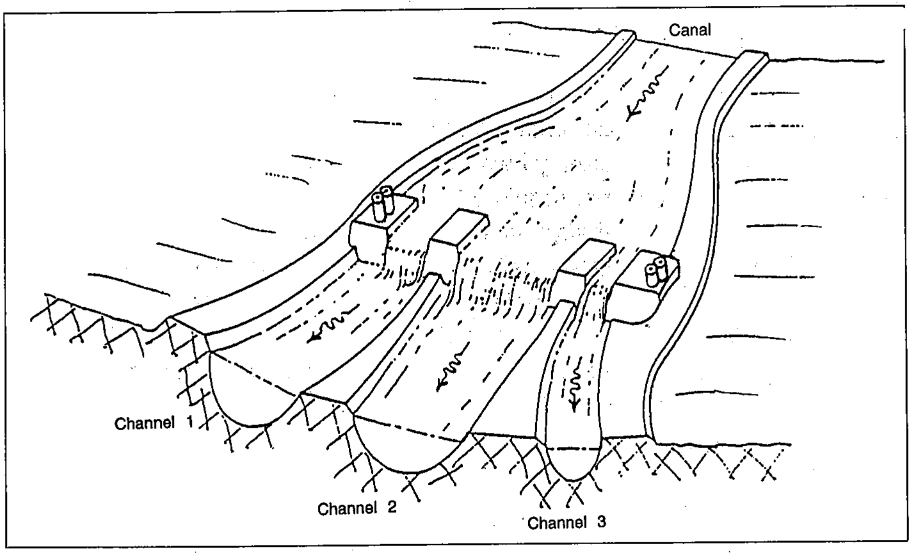
Example 7.4

Flow Division Structures in Bali, Indonesia

Yves Bellekens[57]

Goal: *To divide flow equitably, in accordance with long-established entitlements, at a canal junction. In this case, a modern project replaced proportioning weirs with gated, variable structures. The new system was technically sound but did not have the transparency of operation which was necessary for conflict avoidance; so users demanded restoration of proportioning weirs. This is essential to maintaining community harmony and ensuring sustained irrigated cropping.*

Figure 7.4.1. Perspective view of traditional, wooden, weir-type divisor.



The allocation of irrigation water among subareas of a system should meet crop needs and be equitable. In mountain schemes, flows in canals are highly variable. The main source is often a river with fluctuating discharge. The system may also receive return flows from adjacent rice fields, water from nearby springs, and from overflow structures and drains. A desirable flow division structure must be able to operate automatically under these variable circumstances and divide the flow proportionally at all times.

This example describes traditional, wooden, weir-type divisors and the consequences of their replacement by gated structures and masonry division boxes. It also illustrates the process of modifying or replacing the new structures with concrete weirs and using wooden logs or planks, in the traditional fashion, to apportion the water among subareas. The setting of this example is Bali, Indonesia, already described in Examples 5.1 and 5.3.

The Traditional, Wooden, Weir-Type Divisor

Irrigation systems in Bali have for centuries divided the water among channels using wooden, weir-type divisors. The basis for smooth and sustainable irrigation management is equity in sharing water. Determination of equity in sharing irrigation water is based on the area, soil type, and type of crop which can be profitably grown.

To achieve the fundamental equity requirement in a cost-effective and simple manner, which is understood at all times by all irrigators, *subaks* (farmer organizations) have installed simple wooden weirs (Figure 7.4.1). The water openings

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have the same sill level, therefore the same water depth, but the width is proportional to the water requirements of the respective areas to be served. An irrigator can come at any time, examine the structure, and easily determine how the water division relates to expectations.

The traditional, weir-type structures were replaced with gated divisors by the project. This was done without the involvement of irrigators. The gated divisor is adjustable, and therefore the size of the opening can be varied. The opening is located under the water surface and the sill for opening may be at a different elevation (Figure 7.4.2). Discharge through the gate is turbulent and the gate opening and flow velocities cannot be visually checked by irrigators. This creates unsurmountable difficulties since farmers cannot check if water is shared equitably. Complicated hydraulic formulae and graphs must be used to determine the discharge through the gates and are not easily comprehended by the irrigators. Moreover, gated structures are frequently blocked or clogged with sediment and organic debris present in mountain systems.

Hydraulically the new structures are adequate. However, they fail to meet local cultural conditions of equitable water distribution and fail to reflect physical conditions related to the local mountainous environment where there are significant return flows,

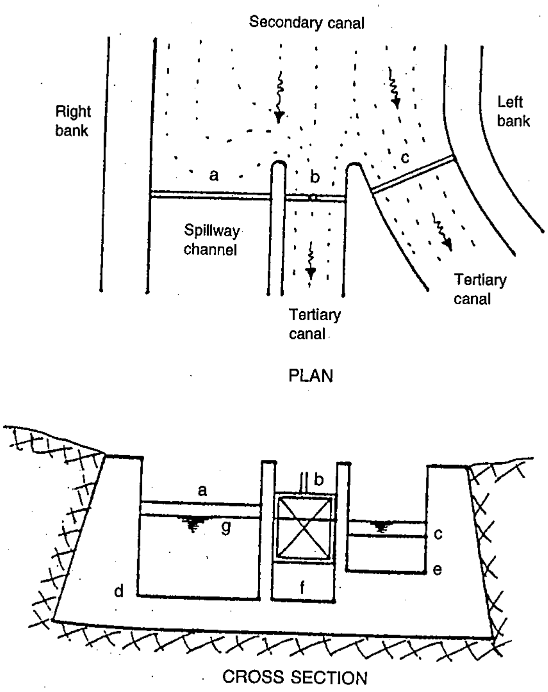


Figure 7.4.2. Schematic view of the gated divisor.

a Spillway for use when there is excess flow in canal
b Gate
c Broad-crested weir
d Main canal floor level
e Subsidiary canal floor level
f High-speed turbulent flow
g Normal water level

Figure 7.4.3. A traditional weir-type divisor made of concrete, which is a modification of a gated flow divisor built at the request of farmers.

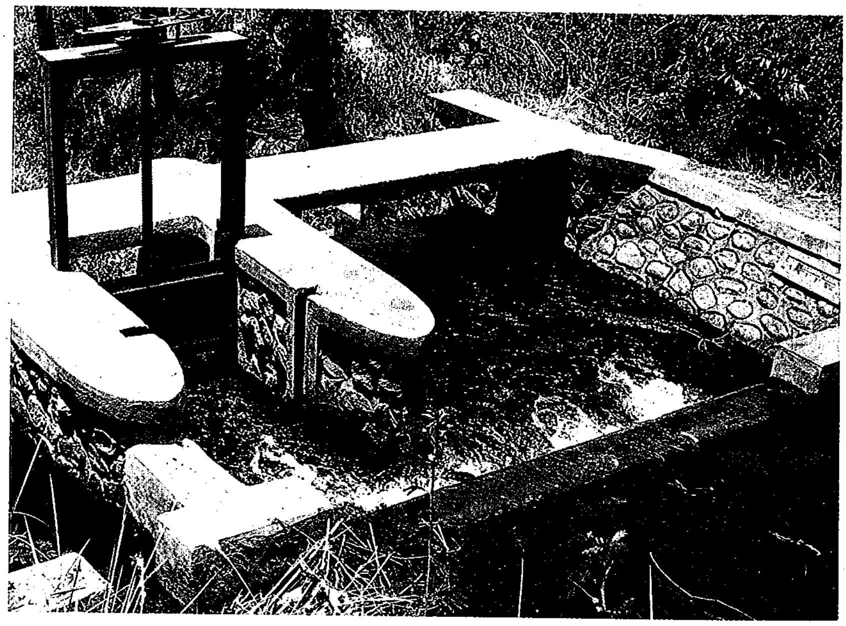


Photo by Y. Bellekens.

Figure 7.4.4. Gated weir modified to operate in the same way as the traditional weir-type divisor.

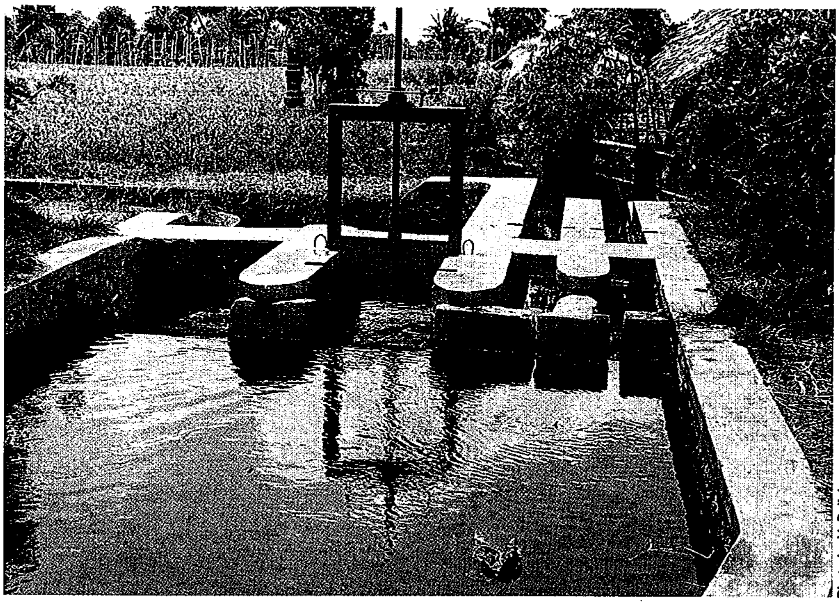


Photo by Y. Bellekens.

and sediment and debris are carried into channels from higher land. As a result, farmers must do significantly more maintenance work. They must check that structures do not get obstructed and overflow causing a breach, which may require sizeable repair work and cause the erosion of valuable agricultural land. Many gated structures were tampered with, damaged, or destroyed by the irrigators when they did not function correctly.

The gated divisors required frequent attendance and specialized care for operation. The irrigators did not understand the operation and rejected the structure as requiring more work for adjusting the gates. Even with the extra work, they were not satisfied that flows were equitably shared as they had been for centuries. Equitable sharing is an important condition for maintaining harmony and avoiding water conflicts. Conflicts would impair the proper functioning of the subaks and threaten sustainability of the irrigation institution and efficient irrigated cropping.

The subak leaders explained to a site investigation team their experience with the gated structures and division boxes and demanded that the permanent division structures be rebuilt to resemble their traditional wooden weirs. Using a measuring tape and a level to make accurate measurements, drawings of design changes were made to convert the gated structures to divisors which operate like the traditional, wooden, weir-type divisors (Figures 7.4.3, 7.4.4 and 7.4.5).

Modifying the gated structures with traditional weirs has worked to the satisfaction of the irrigators. They now have less work in operating and maintaining the modified permanent facilities. It is noted, however, that traditional weirs take more space to build while in mountainous terrain, terraced and flat land is scarce and very valuable to farmers.

Figure 7.4.5. Another gated weir that was modified at irrigators' request.

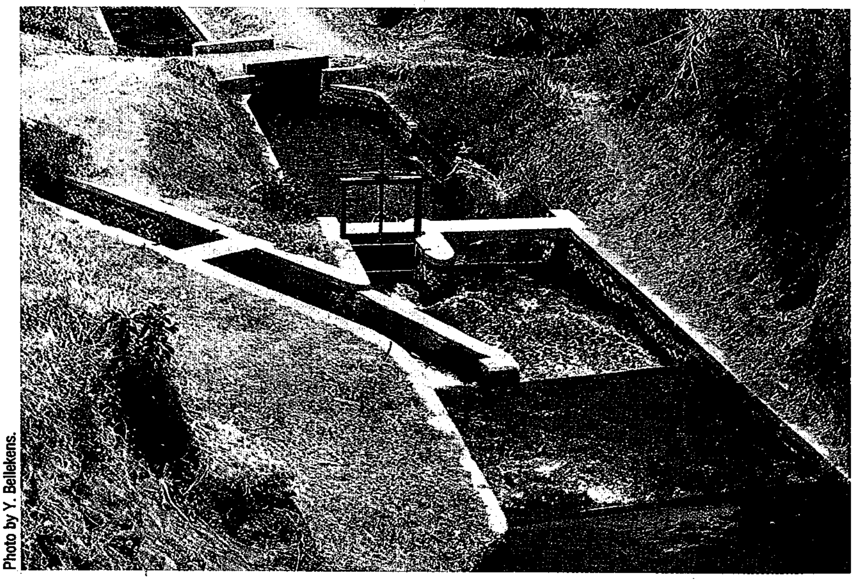


Photo by Y. Bellekens.

Example 7.5

Flow Dividing and Drop Structures Used in Hilly Areas of Ethiopia

Dereje Taye[58]

Goal: *To divide flow equitably at a canal junction without using variable equipment such as gates. Two solutions are proposed, one of which is fully proportional, while the other aims to keep the flows in smaller channels below some upper limit, passing any higher flows down the main canal for safety.*

Most highland irrigation schemes are small in size and are operated by individual farmers. Because of this, little attention has been paid to such schemes and scant design information about them is available in the irrigation literatures.

Even though topography influences design, the intended method of operation of an irrigation system is of equal importance in determining the design. The goal of making operation as simple as possible does not mean that improved methods and practices must be excluded. The aim of irrigation projects is to improve and modernize existing farming practices. The emphasis is on making the design serve its purpose without being too complicated and expensive.

The expected condition is that a development agent, for example a person with a diploma in agricultural science, is available to assist farmers. His responsibility for irrigation is primarily in coordinating operation and maintenance of the scheme. Carrying out the operation and maintenance activities is primarily the responsibility of the scheme beneficiaries, i.e., the farmers. To coordinate maintenance activity, farmers are organized into water users' associations at the scheme level.

The Setting

All the projects in Ethiopia using the structures described here are located in a semiarid climatic region with an annual rainfall of less than 600 mm per year. There are two distinct rainy seasons each year alternating with dry periods. The weather is highly variable and causes serious problems for farmers. Traditionally, farmers plow and sow immediately after the first shower. Though the first rain is often of high intensity, it sometimes ends prematurely causing crop failure and drought. That is why irrigation projects are so important.

Generally, monocropping is practiced. Farmers are used to growing only maize. A demonstration plot set up to train farmers has shown that potatoes, carrots, cabbage, tomatoes and green pepper can also be grown. Nearly all the produce grown is consumed by the farmer and his family. This might be due to the low price for maize in the nearest towns. With low prices, there is not enough income for a farmer to purchase other food items for his family.

The Irrigation Systems

The irrigation systems are all located in highland areas with the altitude ranging from 1,200 to 1,400 m. This area has a steep topography with cultivated slopes ranging from 1 percent to 3 percent. The source of irrigation water is small perennial rivers. The discharge of the rivers is dependent on rainfall and is highly variable though substantial base flow is maintained.

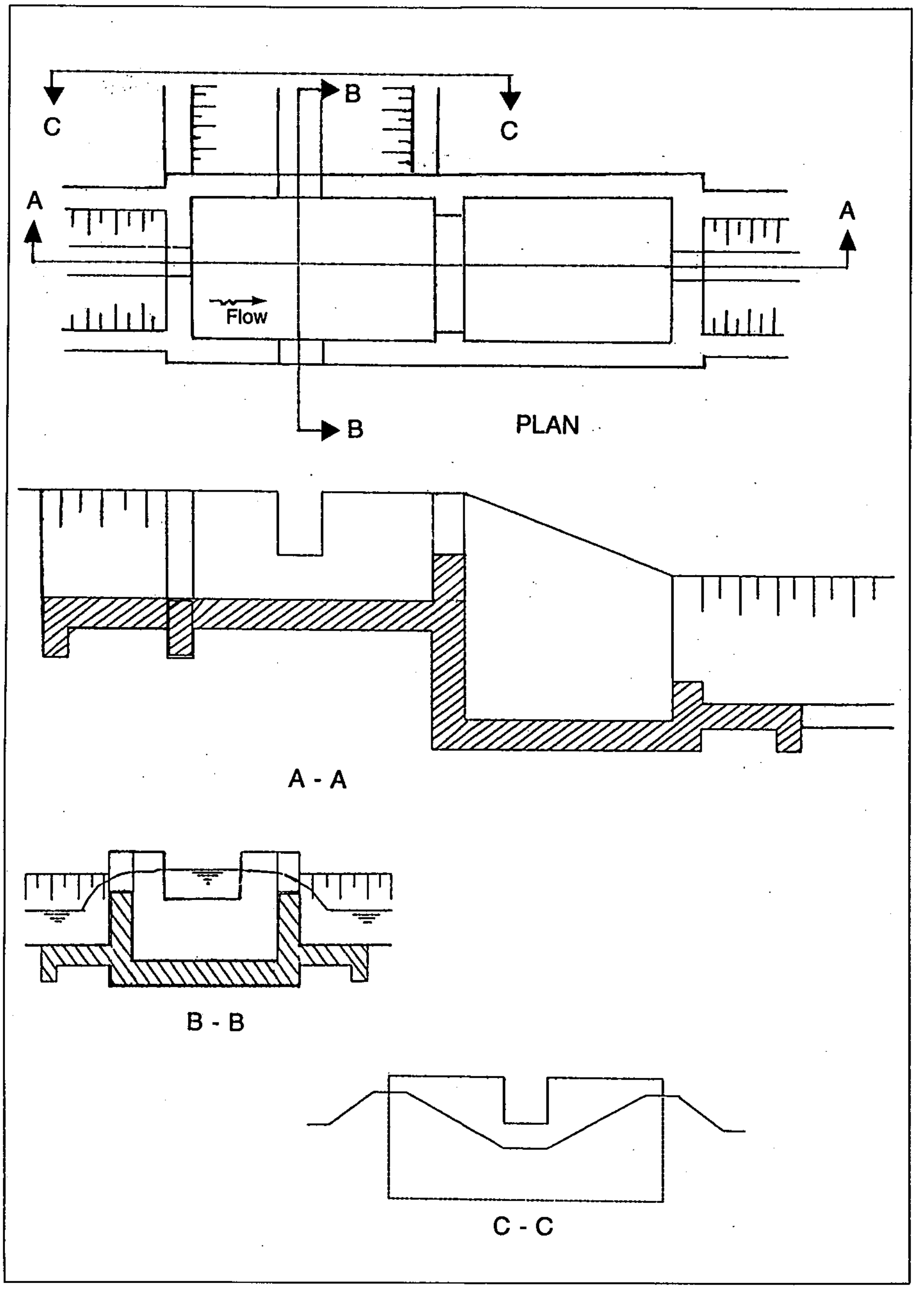
Operation of the schemes is organized by a development agent (DA) who determines the irrigation interval and amount. The DA also helps the farmers in organizing themselves and in job scheduling for maintenance activities. When there is maintenance work beyond the level the farmers

58 Civil Engineer, Addis Ababa, Ethiopia.

are able to handle, the DA will contact the organizations entrusted with assistance.

The water delivery principle is based on demand, as opposed to continuous flow. The demand is assessed, priorities determined, and the schedule is worked out by the DA. Then farmers will be notified as to when they will receive water. To simplify the operational procedures, the amount of water that can be diverted is fixed for each structure. The DA then computes a constant discharge in terms of standard water application depth. The DA only needs to compute the time required to supply the required depth of application. To facilitate the computation, charts are prepared which indicate the required irrigation time for a given application of water.

Figure 7.5.1. Proportional flow division box.

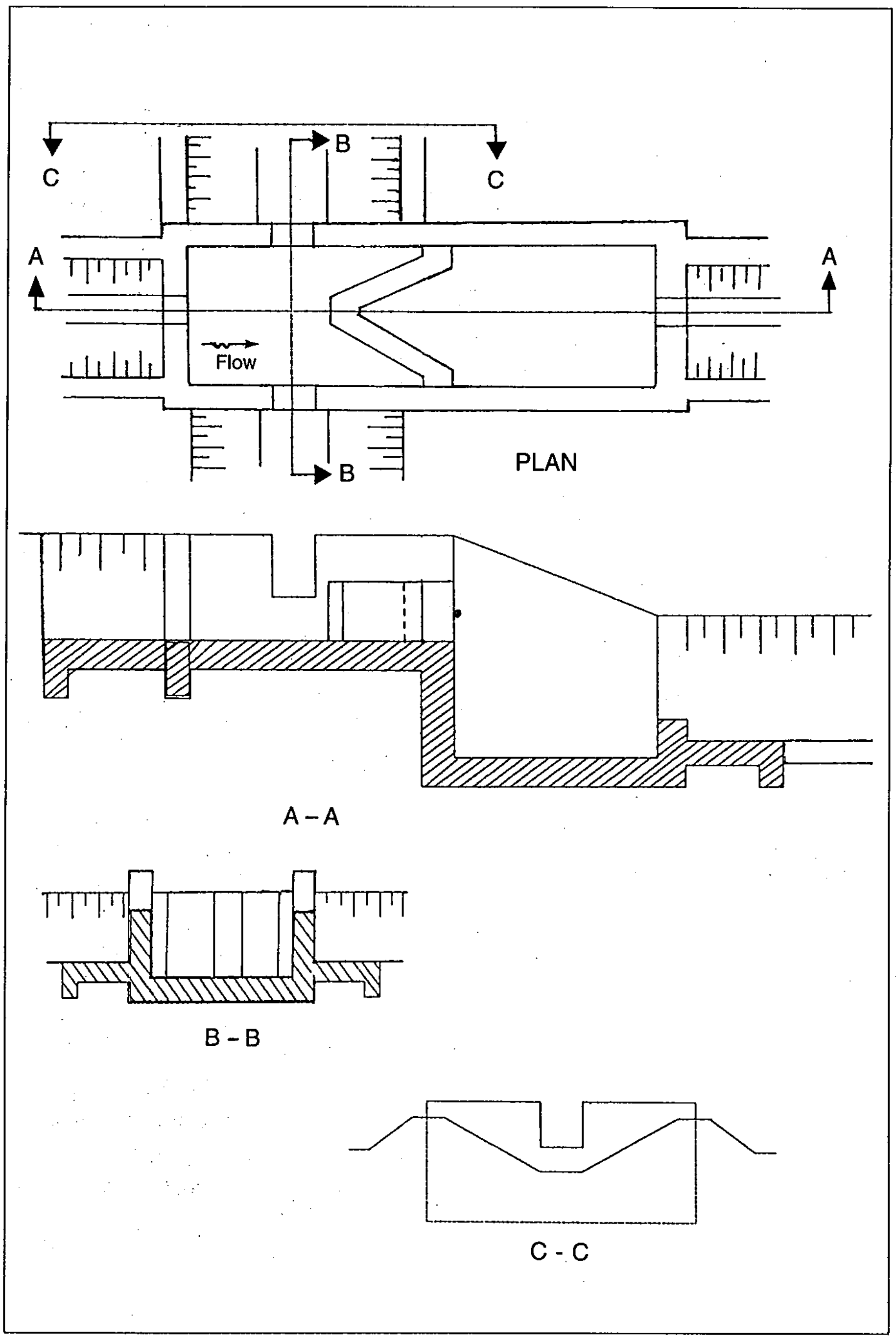


Proportional Flow Dividing Structure

This type of structure has been extensively used in the Ethiopian highlands, primarily to simplify irrigation operation. These systems are small, i.e., less than 200 ha. The purpose of this structure is to divert irrigation water proportionally at each bifurcation point for any amount of flow that exists in the supply canal. Figure 7.5.1 shows a typical division box designed to divide the incoming flow proportionally among the ongoing canal and two branch canals.

The flow to be diverted to the feeder canals is fixed based on the area and expected cropping pattern. The water requirement varies depending on several factors. To deliver water to exact requirement at the right time requires a higher degree of technical and managerial organization which is not expected to exist in the area. Therefore, to simplify operation which ultimately determines the successful utilization of the irrigation water, the proportional dividing structure is preferred.

Figure 7.5.2. Duckbill regulated proportional flow divider.



duration of water application due to lower water deliveries.

Irrigation water is supplied continuously from the main canal to secondary canals through the proportional division box with rotation at the field level. The average landholding is between 0.5 to 1 ha and field-level water distribution by rotation is based as much as possible on the area of landholding. This allows accurate estimation of the water usage on a daily basis.

Figure 7.5.2 shows a regulated proportional flow divider. This structure diverts a relatively fixed amount of irrigation water at the bifurcation point, as determined by the designer, irrespective of the flow in the supply canal. This type of structure has been used where flood water is stored during the rainy season in a tank formed by a dam for use later during drier periods. This type of structure has been used to economize water application without using a complicated operation system.

The regulated division structure economizes not only on the water delivery, but also on the design of the drop structures necessary in the secondary canals. Since the secondary canals are on steep slopes many drop structures are necessary. The regulated proportional flow divider allows design of the drop structures in the secondary canals for exact design flow. Oversizing the structure for safety is not necessary.

The design flow is established by the maximum water requirement that is expected to occur. The structure is designed to deliver the required maximum flow to each canal when the main canal is flowing full. During periods of low water demand, farmers reduce their time of irrigation use. During drought when the discharge in the main canal is less than the design flow, they increase the

Example 7.6

Adjustable, Proportional Main Canal Offtake and Secondary Canal Distribution Box Used in Central Nepal

Dan Spare[59]

Goal: *To divide the flow proportionately between a main channel and two offtakes, in such a way that the selected proportions may be varied, and that any changes can be readily inspected by all participants. Two solutions are illustrated, appropriate to outlets for secondary and tertiary canals, respectively, each using the principle of a proportionally divided weir. In the first, the width of openings is adjustable by reducing openings with vertical stop logs; in the second, the adjustment is by a flexible divisor plate. The second case incorporates a facility for rotational deliveries when water is scarce.*

This example describes two structures designed for a system under construction in central Nepal. The first is an adjustable proportional division structure used to distribute the water from the main canal to secondary canals. The second design is a distribution box for secondary and tertiary canals. This is the same irrigation system as described in Example 6.14.

The Setting

As mentioned in Example 6.14, the irrigation system is located in the Himalayan foothills of Nepal at an elevation of about 600 m. The average annual rainfall is over 1,700 mm. Most of this comes in the warm monsoon months from mid-June to the end of September. Light showers occasionally fall between December and March. Nighttime temperatures in December and January can be as low as 5 °C.

Depending upon available water, farmers traditionally follow different cropping patterns. They prefer to grow as much rice as they can. So where water is plentiful, they will raise two rice crops followed by wheat. When irrigation is not adequate, the monsoon rice crop is followed by wheat and maize in succession. With relatively scarce water, the rice crop is abandoned in order to permit a long-season maize variety to be relay-cropped with millet. This may be followed by wheat if there is sufficient soil moisture. Irrigation or the lack of it is a major factor in the decision making of the crops to be grown. Highly variable and scarce rainfall during the non-monsoon months makes wheat and maize yields quite low and unpredictable.

Landownership by farmers in the area varies considerably, but most holdings are small. In 1982, 82 percent of the households owned less than 0.5 ha. Size of plots is usually quite small and parcels are usually not contiguous. Most farmers have some forest land, some steep grass land and some non-irrigated crop land. Some farmers have land partially irrigated from seasonal stream sources.

Grain production in this mountainous area is insufficient for food requirements of the population. A paved highway in the immediate area allows for the transportation of additional food grains from other areas of Nepal and provides access for fertilizer and seed inputs.

The Irrigation System

A water users' association (WUA) has been formed to manage the user input for system construction. This organization takes full responsibility for operation and maintenance.

59 Irrigation Engineer, United Mission to Nepal, Kathmandu, Nepal.

Figure 7.6.1. Typical main canal offtake with two secondaries.

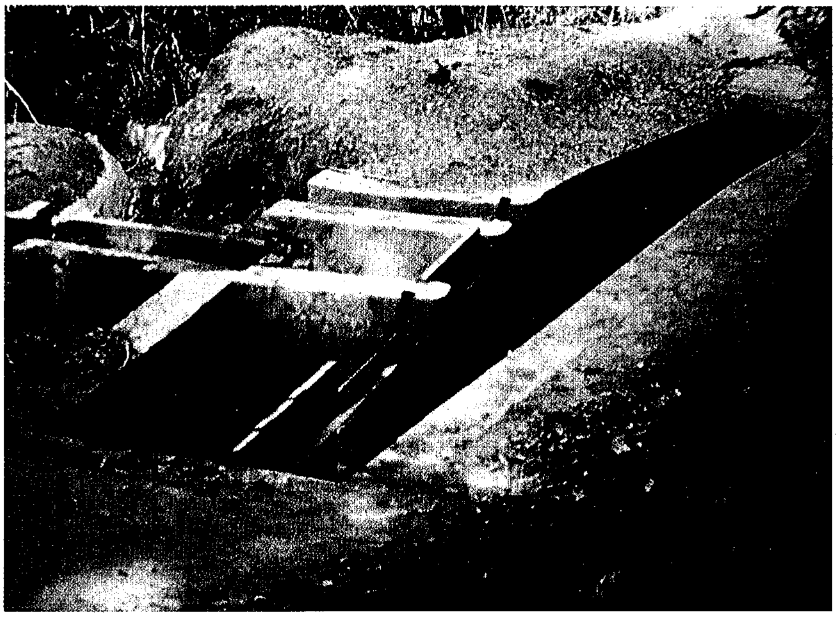


Photo by Dan Spare.

At full discharge, a single share will be about 0.032 l/s. Water distribution is continuous in the main canals. It is normally continuous in the secondary canals as well. When the water supply is limited, the farmers will switch to rotation in the secondary canal.

Details of the relationship of a shared diversion with a hydropower company and other important features describing the system are found in Example 6.14. A unique aspect of this system with respect to agency-assisted irrigation development in Nepal is the concept of transferable water shares.

Persons in the area who want to participate in the benefits of irrigation may purchase "water shares" by their labor during construction or by monetary transaction. Water shares are a transferrable property right, not connected to landownership. Water shares which are not required on one's own land can be leased or sold to another individual. Water is diverted from the river and delivered to the command area through a tunnel. The headworks and tunnel structures are common to both the hydropower use and irrigation.

The adjustable, proportional main canal offtake is located near the penstock of the hydroelectric plant. Water is delivered to the irrigation system, to the east and west main canals, according to an agreement between the hydroelectric company and the *Andhi Khola* Water Users' Association (AKWUA). The main canals are gravity canals serving areas east and west of the structure.

From the two main canals, water is divided proportionally among secondary canals and ultimately to individual users according to the total shares of water owned below each division point.

STRUCTURE 1: THE ADJUSTABLE, PROPORTIONAL MAIN CANAL OFFTAKE

This structure is necessary to accommodate the farmers' desire to occasionally assign their water shares to other parts of the command area. Figure 7.6.2 gives the plan and cross section of the first offtake near the penstock. Figure 7.6.1 shows a typical main canal offtake where the water is divided proportionally between the main canal and two secondary canals.

Division of water by proportion is accomplished by placing vertical wooden "stop logs" to cover part of the opening. The width of opening is determined by the proportion of shares being allocated to the secondary and the ongoing main canal at a particular time.

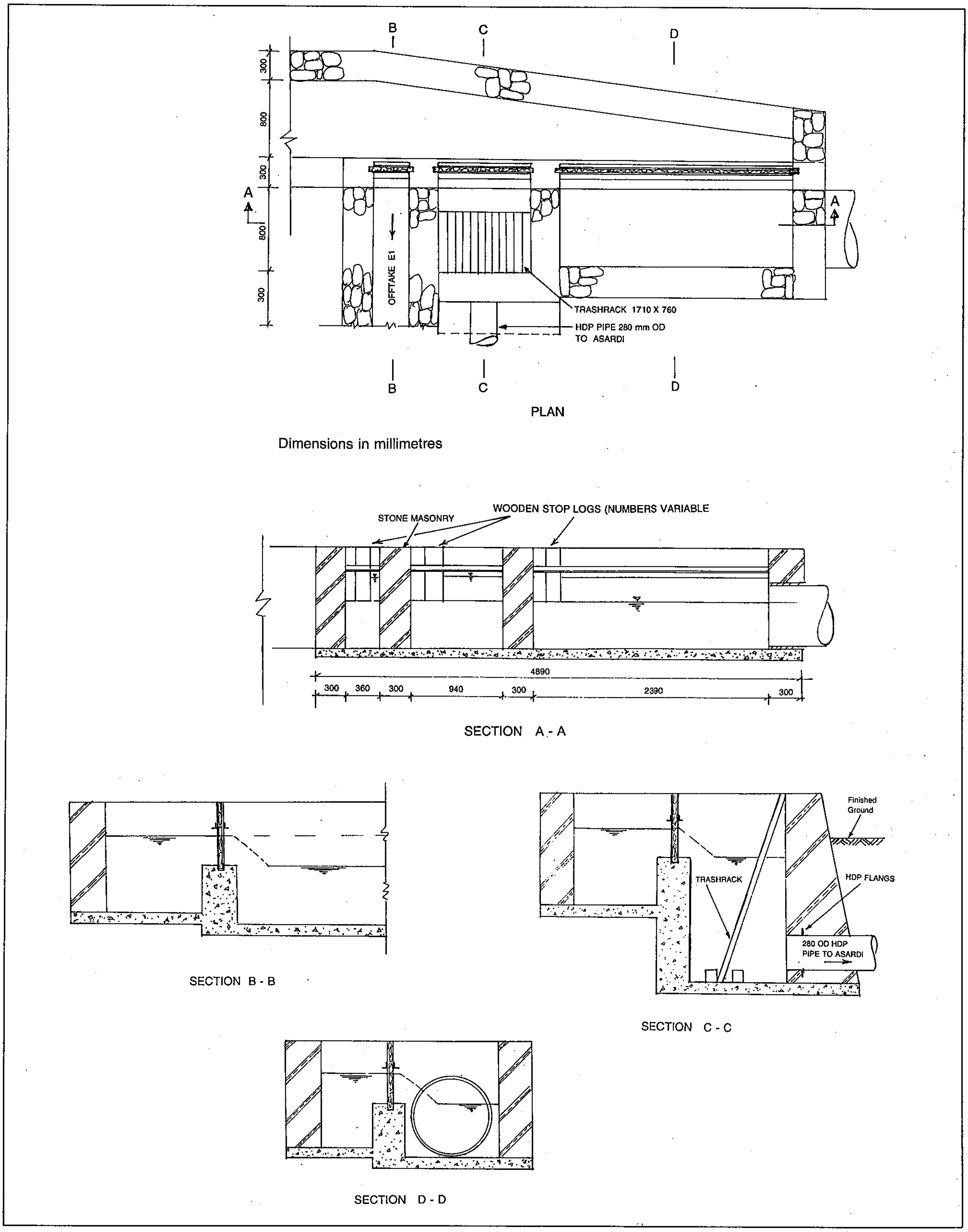
The main canal follows the contour for much of its length. However, since the command area is much lower than the main canal, a loss of 0.5 to 1.0 m head for this structure was considered tolerable.

The irrigators have begun to operate and maintain these structures. The only maintenance is cleaning of the canal. For operation, setting of the proper proportions is the responsibility of AKWUA. The farmers must be able to have access to and compare the opening size at will against the posted information to confirm proper distribution of water shares.

Selection among Alternative Options

The division of water to different locations is not a new or strange activity for farmers. A traditional

Figure 7.6.2. Plan and cross section of the adjustable, proportional main canal offtake.



method for dividing water flows to various fields or sections of an irrigated area involves the use of a log placed in a stream perpendicular to the current. The log has rectangular notches, the lengths of which are determined by the respective proportions assigned to each outflowing stream. This method has worked well for farmers in irrigation systems that they have built. The main drawback to this method is that adjustments requiring the change of opening were difficult. Changes can be done only a limited number of times before a new log is required so it is suited to systems where water rights do not change frequently.

The adjustable structure designed to perform the same function uses stop logs that slide vertically into a supporting frame to modify the size of the respective openings. Leakage of water under or between the stop logs is sealed with mud. Simplicity of offtake design was important. Nonuse of moving metal components that would rust or jam was a high priority. Minimum mechanical maintenance was highly desirable. These requirements were satisfied by the design using removable stop logs.

The offtake is operated by the AKWUA office personnel who do not have technical training. The design is such that these persons can understand the principles of the opening settings and perform the necessary calculations. The widths of openings are displayed in a public place and any AKWUA member can check the openings at any time they desire.

The maintenance expected for this structure is the cleaning of the tank. Drain holes were provided below the stop logs for this purpose. These are plugged during normal operation.

Hydraulic Considerations

Proper hydraulic design required estimation of the expected water duty and the area to be irrigated, to determine the design discharge. The height of the channel above the bottom surface of the weir, and the length of the weir were the primary parameters to be determined while it was assumed that the length of each opening would represent full irrigation of the assumed command area and, if the share distribution did not later correspond to that estimate, stop logs would be fitted to represent the required share distribution proportion.

Structural Considerations

The channel iron supporting the stop logs was sized to withstand the force of a full tank of water on the upstream side. Two important installation requirements were that the sill of each opening be at the same level and that each sill is level from one end to the other. The level tolerances were set at one millimeter. The overall workmanship of the sides and bottom surfaces of the weir should be of uniform quality to ensure that the weir functions accurately.

The first offtake structure was of reinforced concrete as it was situated on a slope which had demonstrated some instability. The steel frames for supporting the stop logs and establishing the sill were fabricated in a central workshop and delivered to the site by truck. After installation, the frames are immovable.

Only the wooden stop logs remain vulnerable to tampering or theft. These stop logs were made of *saal*, a very hard wood, resistant to deterioration in a humid environment. Even so, they were coated with bitumen for additional protection.

The stop log system has worked well. The only further refinement suggested is that fine adjustment of width should be done by wedging a steel sheet to the exact width required. The stop logs can only provide incremental adjustments.

Cleaning of the tank was done once a year since operations began. Two further offtakes have since been constructed at the heads of two secondary canals. For these, plain concrete was used in the floors and support pillars for the steel structures. The rest of the walls were made of stone masonry.

During the first months of operation, people (especially children) tended to play with the stop logs. This tendency has gradually diminished as the structure has lost its novelty. Had this problem not been resolved, fencing of the structure would have been considered which would not have been desirable since it would have prevented easy, unannounced inspection of stop log settings by the irrigators. The farmers seem satisfied with the functionality of the structure.

During construction of the first offtake, work was supervised by an experienced technician. Most of the structure was of good quality. However, the steel stop log frame had to be removed and reset because it did not meet the level of tolerance desired. Special emphasis must be given to this detail in the designers' instructions to those handling construction.

STRUCTURE 2: SECONDARY CANAL DISTRIBUTION BOX

Distribution boxes have been installed in secondary canals to allow proportional division of the flow. The structure should be designed to enable occasional changes in proportion and occasional shifts to rotational flow on the secondary canal. Figure 7.6.3 shows the configuration of the distribution box.

Water entering the structure drops over a level sill made of brick. Two heavy-gauge, galvanized steel sheets divide the stream of water as it drops over the sill. The brick sill is covered with cement mortar plaster to reduce the gap between the plate and sill to the minimum possible in order to reduce leakage. The upstream end of the steel sheets are adjustable. They are held in position by a slotted angle iron and the relative portion of flow can be adjusted by loosening the angle and deflecting the steel sheet to either side, into the desired slot, thus changing the relative size of the openings.

Wooden stop logs are placed on the outlet side of the structure to shift the flow among the three different channels. Figure 7.6.4 illustrates the nine possible configurations of the stop logs. The adjustable steel plates allow shifting of shares among secondary canals during continuous flow irrigation. The primary purpose of the stop logs is to facilitate rotational flow. The secondary canal committee has responsibility to operate and maintain the distribution box.

To determine the design discharge for the secondary canal, the technical staff worked with the farmers and estimated the total area that would be irrigated. A water duty of 3 l/s per ha for previously nonirrigated land and 1 l/s per ha for land which had some previous irrigation source was then used to compute the design discharge. It is generally assumed that rotation will occasionally occur so the secondary and tertiary canals are sized to convey the full secondary flow. The farmers' suggestions and acceptance of the design details for the secondary canal are essential and actively solicited.

To facilitate construction, the channels for supporting the stop logs are welded together to form a frame. This is done in a workshop where alignment accuracy can be controlled. After setting the frame in place and leveling it, the plain concrete base which securely anchors the frame is poured. The masonry walls and entry sill are then built on the concrete base.

The principle of the proportional divider is known to the farmers of this area of Nepal. A traditional method used by irrigators to divide water flows to different subareas is the use of a saacho, a wooden log with rectangular slots of various widths laid in a canal bed perpendicular to the water flow. The widths of the slots are determined by the agreed proportions of water to be delivered to respective subareas.

By using this same method of proportional division, the farmers can quickly master operational details with confidence. The proportional division of the flow can easily be inspected at any time to check that the openings are properly set.

A door hinged on a vertical axis was considered as a possible solution for adjusting the openings. However, moving parts are notoriously troublesome, so it was decided to attach the galvanized sheet to the steel frame with screws on the downstream edge. The upstream edge is held in place with a notch as shown in Figure 7.6.5.

The secondary canal committee is responsible for all operations of the canal and the organizing of maintenance. The settings for the distribution box can be calculated in the office if the responsible persons are not able to do it in the field. However, the plan is to educate the general membership on the calculation methods as widely as possible so that they will be able to hold their representatives responsible for correct settings.

Primary maintenance activities are the cleaning of the pond upstream of the weir, removal of trash from the structure, and checking on the proportioning sheet and placement of stop logs.

Six distribution boxes have been installed. More are being made for other secondary canals, and improvements are continually being made. The cost, including labor and materials, is about US$50 per unit.

Figure 7.6.3. Plan and cross section of the secondary canal distribution box.

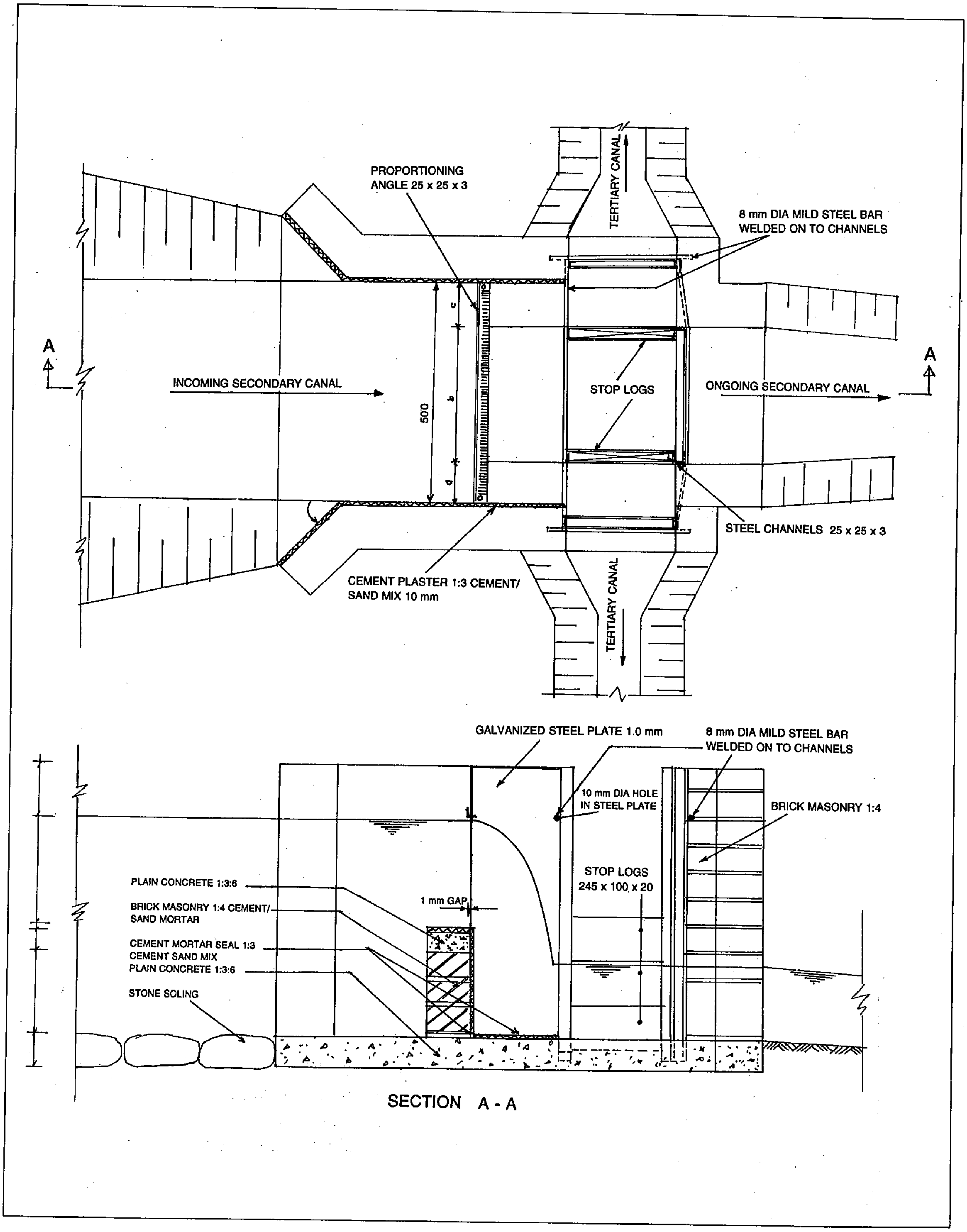
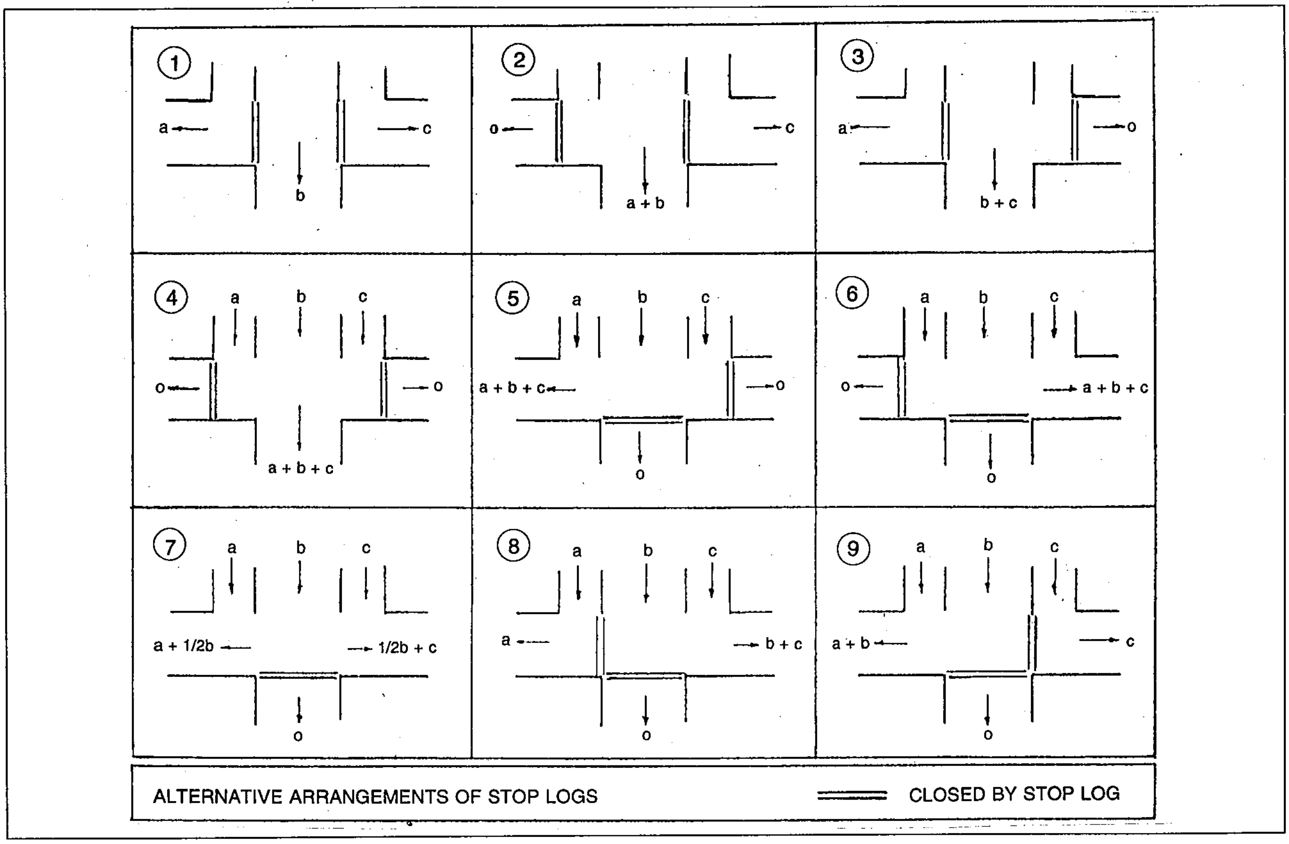


Figure 7.6.4. Alternative arrangements of stop logs in the secondary canal distribution box.



A simple method was needed to seal the upstream and bottom edges of the proportioning sheet to prevent lateral movement of water between streams. Soil cement was found to give a sufficiently durable seal if left to set for a day without flowing water. For resetting the plate, it is easy to chip the soil cement from concrete and cement plaster surfaces.

The division boxes installed to date appear to be holding up to wear and tear, except for one point; the galvanized proportioning sheet needs to be fastened very firmly—several have broken loose during adjustment.

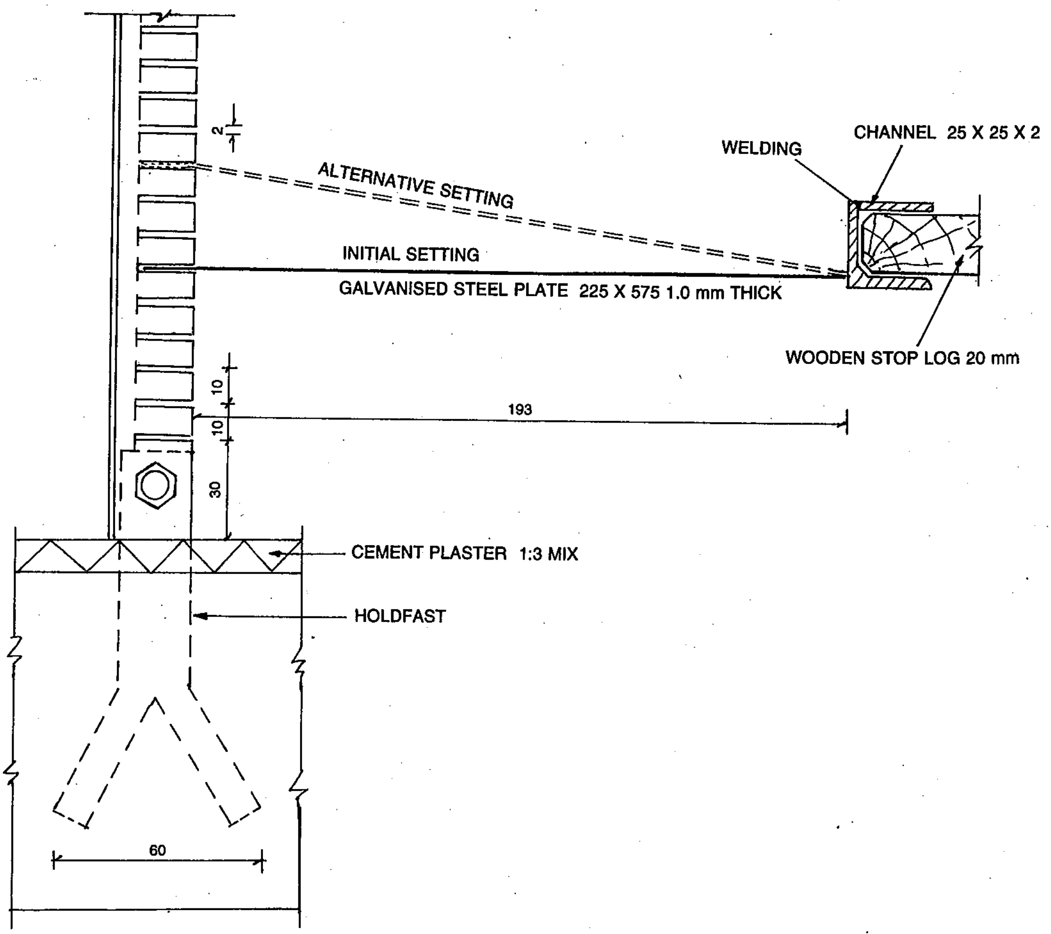
This distribution box is presently designed to accommodate and divide total flows between 10 and 100 l/s. One limitation relates to the minimum flow for any of the three subdivided streams. Ideally, the structure would have been tested in a hydraulic laboratory to determine operational limits. But lacking that, the criterion used is not to divide less than 10 percent of the total flow to any of the substreams lest there be inaccurate division of flow due to edge contraction. Practically, a width of less than 50 mm will very easily block even with leaves or small twigs in the water.

For accurate operation of the distribution box, a "ponding area" is made upstream of the weir in order to create conditions conducive to laminar flow over the weir, thus increasing accuracy of the weir proportioning function.

The irrigators do not yet understand the need to keep the pond immediately upstream of the weir cleaned out. It has filled with debris up to the level of the weir in most cases.

The stop logs can be easily removed. Methods to make them more secure seem to be more costly than the worth of occasional replacement. The secondary committee needs to have full responsibility for them. Finding a solution to this problem should be left to the irrigators.

Figure 7.6.5. Proportional divisor plate for secondary canal distribution box.



Example 7.7

Irrigation and Water Distribution in Mountainous Areas of Himachal Pradesh

Ramchand Oad[60]

Goal: *To modify certain existing approaches to canal layout, so as to make them more amenable to equitable, least-cost management by farmers' groups. Two cases are illustrated: a gravity flow system, and a lift pumping system. In one type, the existing standard approach leads to water losses and inequitable deliveries; in the other, it leads to high operating costs and difficulties in organizing the water distribution.*

In mountainous irrigation systems with many small farmers, it is quite impossible for an agency-managed delivery canal to supply water individually to each and every farmer. It is, therefore, desirable that the farmers organize themselves into groups so that the delivery system management can distribute water among relatively few turnouts serving farmers' groups.

Design of the water distribution system is critical to successful irrigation management; it must satisfy needs of both the water supply agency and the farmers, as far as possible. Farmers will want to receive their due share of water at the right time, and the agency will want the design to exercise effective control for a fair water distribution among various farmers' groups. The design of a water distribution system in mountainous areas is more challenging because the lateral distribution lines have a steep slope due to the delivery canal being oriented along a contour for nonerosive flow velocity. The purpose of this paper is to document experiences with water distribution designs, in the gravity flow and lift irrigation systems of the northwest Himalayas.

The Setting

Himachal Pradesh in India is a mountain state, located in the transition zone between the plains and the high Himalayas. The land elevations range from 400 m to 7,000 m above sea level. Much of the land is characterized by small narrow valleys, steep hillsides and intensive farm terracing for agriculture. Population pressure on the land area is high and the landholdings of most cultivators are small, about one hectare.

The high population pressure has resulted in an increased emphasis, on the part of the State Government, on assistance to farming communities to develop and efficiently manage irrigation facilities. Water for irrigation is usually obtained by surface diversion from small mountain streams and, in a limited number of cases, by lifting from major rivers such as the Sutlej and the Beas. The average annual rainfall is about 1,130 mm, of which about 75 percent occurs during the monsoon months from June to October and the remaining 25 percent occurs in the dry season from November to March. With improved irrigation, vegetable crops are very profitable because vegetables can be grown in the mountains at times when they are out of season in the plains.

Water Distribution in Gravity Flow Systems

The layout of a typical gravity flow irrigation scheme is given in Figure 7.7.1. The system is located in very rugged and steep topography with slopes of about 50 percent. The land elevations rise from 1,000 m at the River Sutlej to about 1,700 m near the main canal intake. The irrigation scheme diverts water from a stream by means of a diversion weir to irrigate about 85 ha of land. The diverted water is

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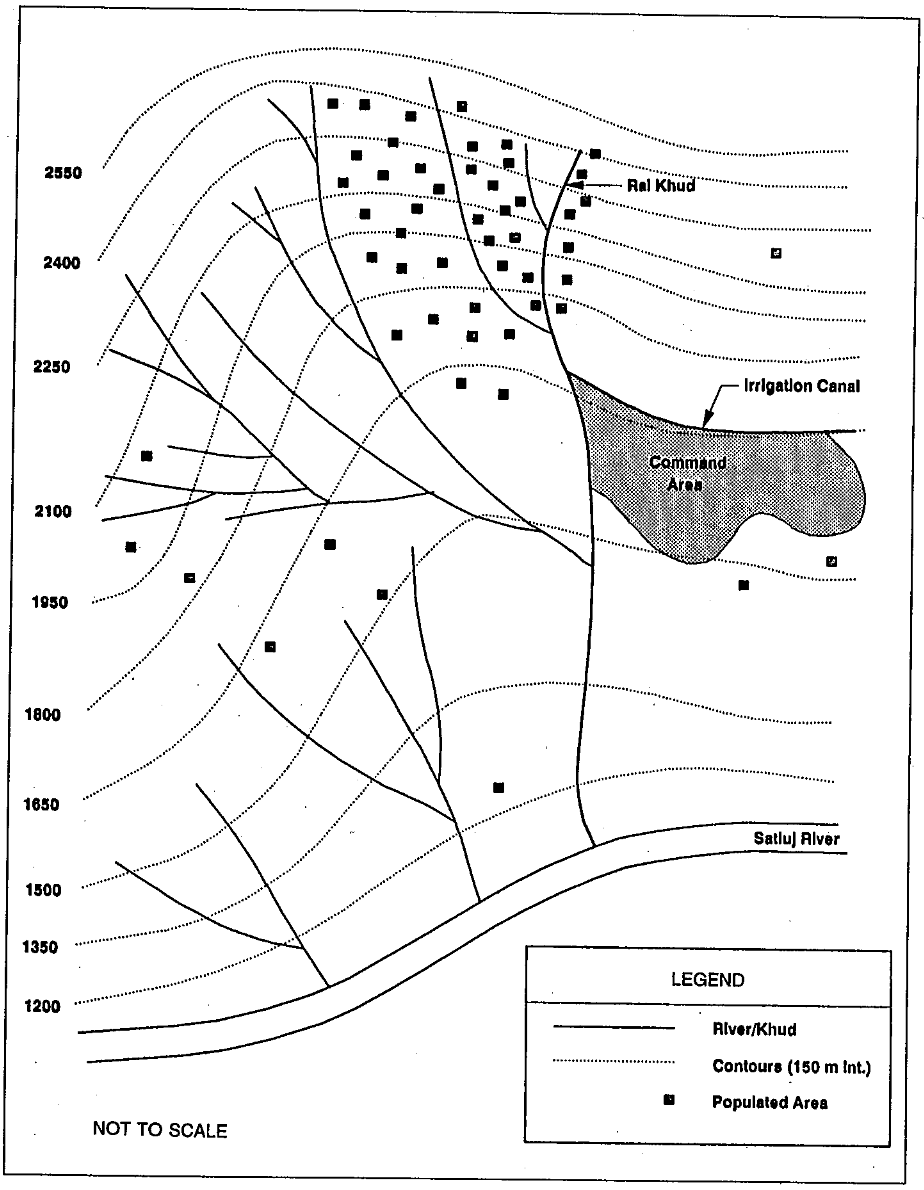
Figure 7.7.1. Layout of a gravity flow irrigation scheme in Himachal Pradesh.



limitations.

For water distribution among turnout groups, there is no flow regulation capability at the turnouts because the flow through the turnouts is not true orifice flow. The turnouts are essentially holes in the channel side which can either be completely opened or plugged. Without proper flow measurement and regulation, it is not possible to manage irrigation deliveries to the turnout groups according to crop water requirements.

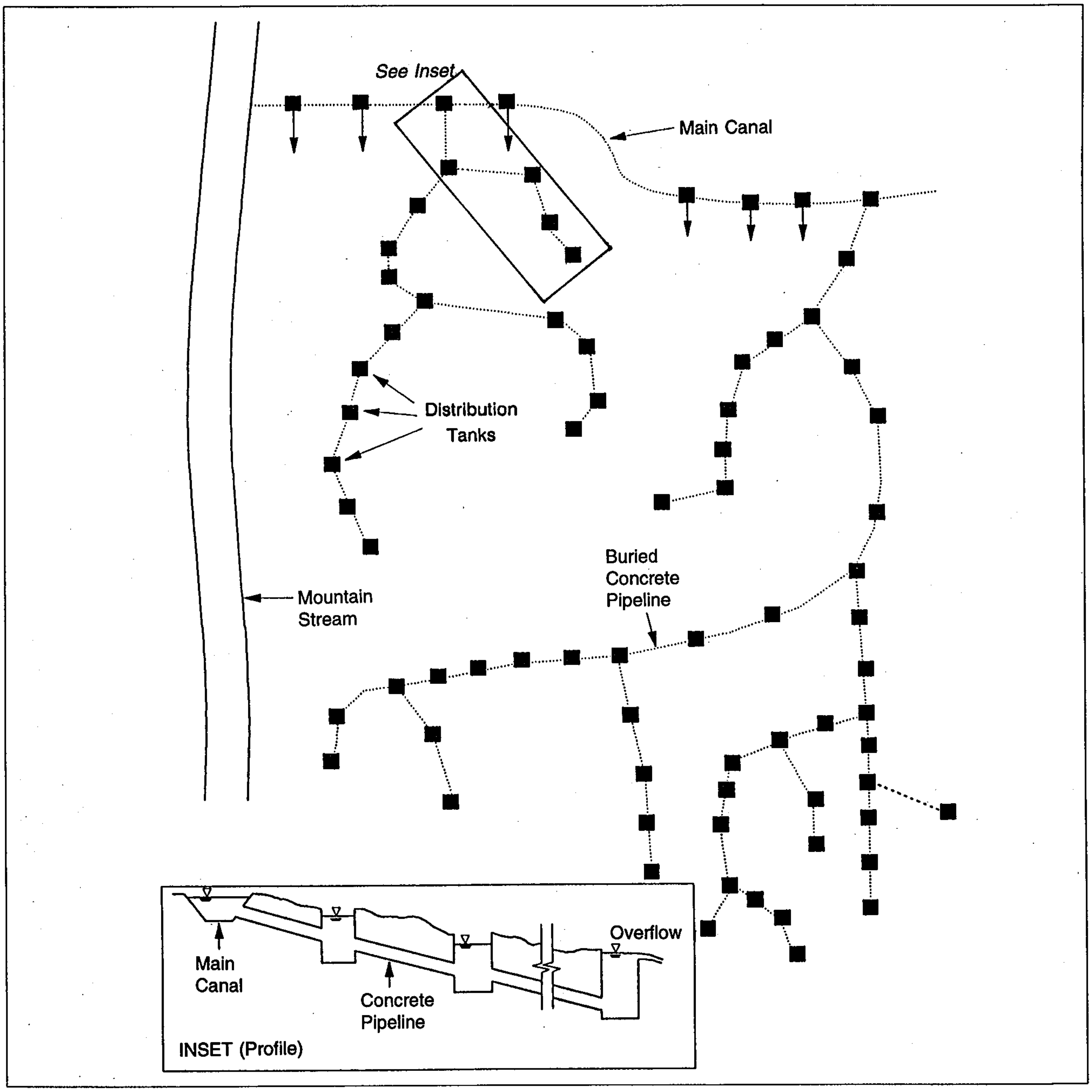
Within a turnout area, the number of farmers and therefore that of the tanks ranges from 50 to 100. Because of the large number of farmers and the absence of control valves in the pipelines, it is difficult to organize rotational distribution of water when the water supply is short. Also, because of the steep slope, water enters mainly into the tank which is plugged on the exit side (last tank on a rotation), and then spills from this tank (Figure 7.7.2 inset). In all other upstream tanks, the water level remains too low for the farmers to use their siphon pipes. When water is available in the main canal, farmers of adjacent landholdings put small diameter pipes into the main canal and convey water to their lands. Farmers whose lands are downslope either do not get water or it flows to them via their upslope neighbors.

A better design for water distribution in mountainous areas is to use a set of contour channels oriented parallel to each other at a certain

conveyed to the agricultural lands by a main canal whose design discharge is 60 l/s.

A design common to many irrigation schemes for water distribution among farmers' groups is shown in Figure 7.7.2. Water from the main canal is delivered to farmers' groups through orifice turnouts and concrete pipelines. Each pipeline has a number of tanks situated on it and each tank serves one landholding of about 0.5 ha. The original design envisioned water entering and filling all the tanks on a pipeline so that farmers could apply it to their lands by means of siphon tubes. In practice, the design has major physical and organizational

Figure 7.7.2. Present water distribution design of the gravity flow irrigation schemes in Himachal Pradesh.



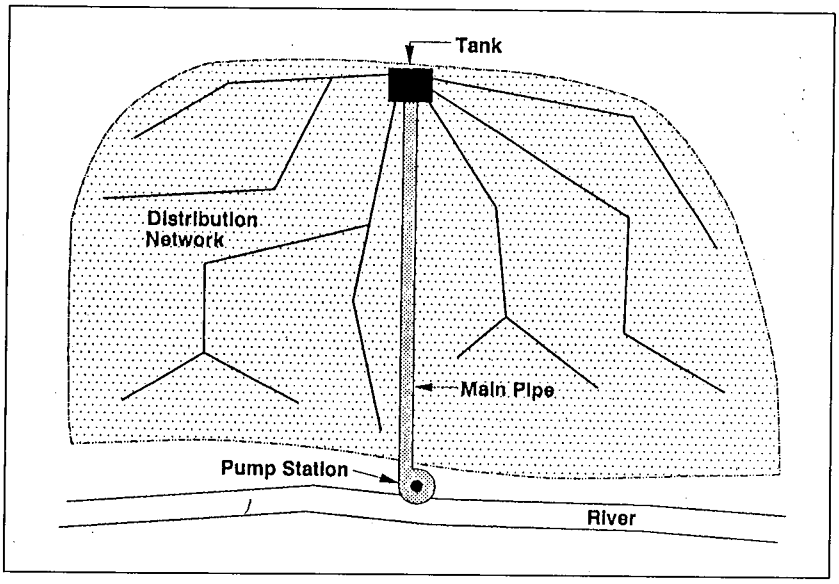
vertical interval. Because the contour channels will be oriented across the mountain slope, flow velocity will be much smaller compared to the situation when the distribution lines run down the slope. These parallel contour channels can receive water from the main diversion by means of a chute, buried pipeline or, as is the case in Figure 7.7.1, through a natural stream. Farmers can take water from the channels by means of small-diameter, flexible rubber pipes.

The use of parallel contour channels is common in mountainous areas of other countries such as Indonesia and Nepal. The distribution system consisting of two or three parallel contour channels divides the overall command area into small channel commands and, as such, management of rotational water distribution is possible. The physical structures are simple, open channels which are easily maintained by the farming communities without external help. Also, irrigation water use is efficient because the lower channels will pick up a significant portion of the return flow from the higher lands.

Water Distribution in Lift Irrigation Systems

The command area in lift irrigation schemes is usually an inclined plane with the slope towards the river. The required water is lifted from the river to a single point at the top of the command area (Figure 7.7.3). Typical lifts are about 100 to 300 m. At this highest point, a distribution tank is made and water is distributed to all farmers from this tank.

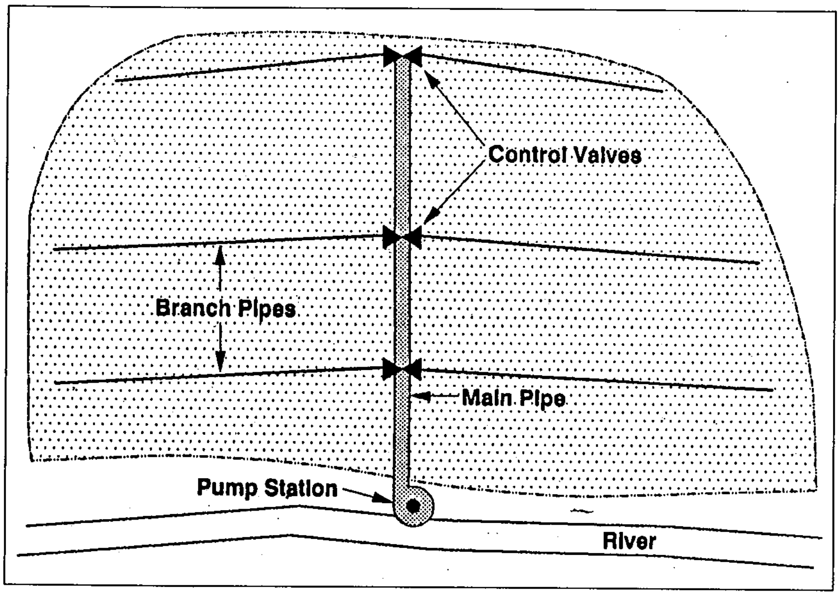
Figure 7.7.3. Existing water distribution system in lift irrigation schemes in Himachal Pradesh.



The design approach results in long distribution lines involving many farmers on each line, and some farmers are far away from the source (the distribution tank). With this system design, it is very difficult for the farmers to organize for water distribution. Also, the system design results in high energy costs of operation because all the water is raised to the highest point.

A more desirable design for effective management would desegregate the command area into small distribution units. To accomplish this management objective, branch pipes (or open channels) can take water at suitable intervals from the main riser pipe (Figure 7.7.4). Each branch pipe (or channel) can deliver water to one distribution unit with a control valve at the intake point. In addition to simplifying water distribution among farmers, the variable-head pumping design greatly decreases the energy costs for pump operation. In this design for lift irrigation schemes (Figure 7.7.4), water is lifted through the total rise only one-third of the total rotational time. It is lifted to one-third of the rise for 33 percent of the time, and to two-thirds of the total rise for the remaining 33 percent of the time. As such, the energy costs will decrease by a factor of one-third.

Figure 7.7.4. Proposed water distribution design for lift irrigation schemes in Himachal Pradesh.



To support this water distribution design, the pump must be designed to deliver water at variable heads. This is possible since the affinity laws governing pump performance state that the pumping head varies directly as the square of the impeller speed. The pump speed can be changed by using variable speed drives on motors, or by using variable frequency drives that change the motor speed by changing the electric cycles. An alternative to using variable speed or variable frequency drives is to install two or three smaller pumps instead of one large pump. When operated in series, the total pumping head is the summation of the individual energy heads.

Example 7.8

Discharge Regulator for Pressurized Systems in Haryana, India

Christopher A. Scott[61]

Goal: *To reduce conflicts over water shares by incorporating a visible water measuring device in a 38 ha irrigation system where water is delivered to the fields by buried pipelines under gravity. The system is very deficient in water, and the chosen device worked until a drought year, when some irrigators damaged and bypassed it. The damaging action may indicate that the water sharing principle was not in conformity with the power structure of the irrigating community.*

Timed rotational irrigation can result in conflict if the discharge in the conveyance system is perceived to vary. The technical solution to equitable distribution under timed rotation is to measure and regulate discharge. Measuring devices which appeal to irrigators' common sense are crucial in this regard. Examples include simple flumes and proportioning weirs to measure and divide discharge in open channels. However, in upland irrigation systems where pressurized delivery is common, the measurement of discharge can be difficult.

This example describes the initial success and subsequent failure of an open flume with a rectangular notch weir to measure discharge in a low-head pressurized system. The example shown in Figure 7.8.1 is from Dhamala village in the Shivalik Hills, Haryana, India.

Set in a flume, the weir measures discharge which is regulated by manual operation of the valve of the structure's intake pipe (Figure 7.8.2). The flume is amenable to public inspection (and to tampering). It also acts as a sediment trap for discharge entering the distributary pipe from the main reservoir. However, periodic maintenance is required.

Built in 1983-84, the pressurized, gravity irrigation system in Dhamala is jointly managed by local users and the Forest Department. The flume performed well for several years when the system operated on a timed rotational supply (warabandi) basis. Gradually, however, the supply became more demand-based. In the summer of 1988, when the reservoir dropped to its lowest level ever, the discharge regulator was tampered with, as evidenced in Figure 7.8.1, where a hole made near the base of the weir can be seen. Nevertheless, the benefits, compared to the cost of the structure estimated at US$150 in 1990, do appear to have justified its temporary use.

The Setting

Average annual rainfall in Dhamala is 1,100 mm. At an elevation of approximately 600 m, potential evaporation exceeds rainfall in all the months except July and August. The predominant silt loam and silty clay loam soils have low infiltration rates

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(2 to 7 mm/day in undisturbed, saturated conditions), and pH values as high as 9.4. Drainage from agricultural land is a problem. Steep slopes with degraded natural vegetative cover generate high runoff in intense monsoon downpours. In 1982, erosion rates in the catchment areas above Dhamala were as high as 900 t/ha per year. The grazing of livestock in the watersheds has exacerbated degradation.

Kul (open-channel) irrigation from the Kaushalya River, which emanates from the Himachal Himalaya, is historically practiced only in the neighboring Lohgarh village. Prevailing water allocation practices in Lohgarh are based on landholding, with distribution on a warabandi schedule of timed rotations. At the tail of the kul, Lohgarh receives significantly less than its allocated share of water. Lohgarh kul irrigators often seek to increase their share of discharge by creating temporary obstructions to increase the head, and correspondingly the discharge, at their takeoff.

Dhamala has a mixed-caste composition, with agriculture dominated by Jat Sikhs. Landholdings in Dhamala average less than 1 ha per household, with just under 60 percent of all households owning no land at all. Comprising 12 percent and 13 percent, respectively, of the average household income in Dhamala, agriculture and livestock both rely on irrigation. In an average household, 70 percent of the income comes from household members working in nearby urban areas. Agriculture in Dhamala is a mix of market-oriented and subsistence production. Dhamala is located on a permanent road, with easy access to several urban markets.

Sale of milk is an important source of income. The primary kharif (June-October) crops are maize, rice and sugarcane while rabi (November-March) crops are wheat and berseem. Field preparation involves deep tillage and the incorporation of large

Figure 7.8.1. Discharge regulator for pressurized distribution system in Haryana, India.

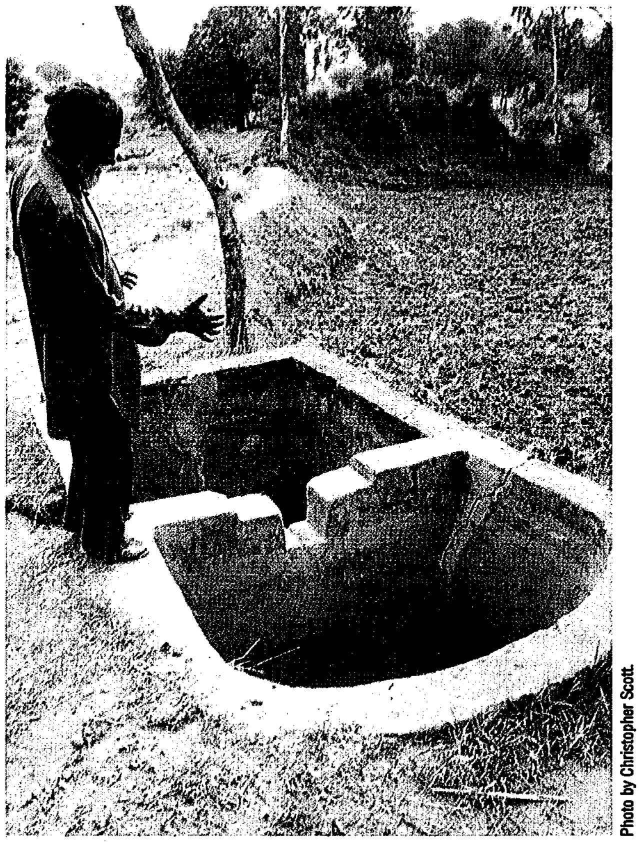
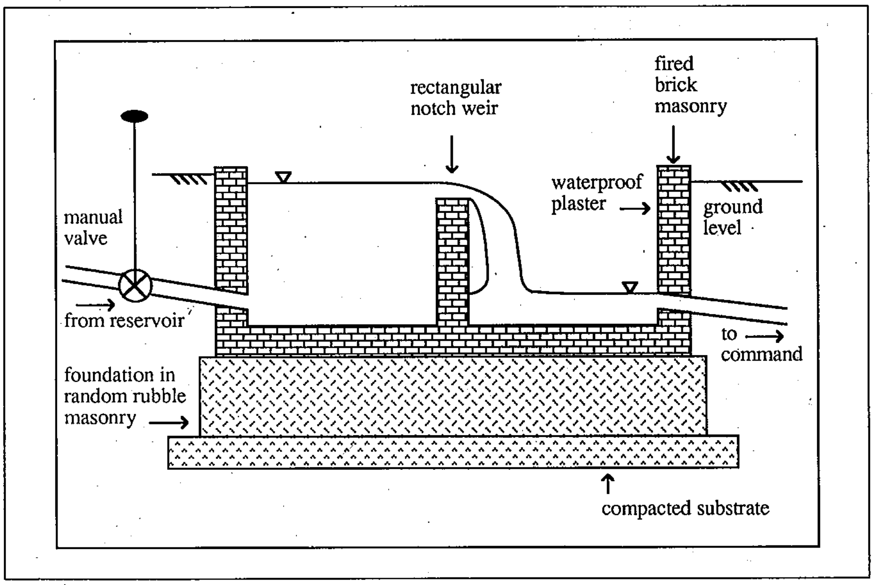


Figure 7.8.2. Longitudinal view of a discharge regulator for a pressurized distribution system.



quantities of farmyard manure, available because livestock are stall-fed. Nitrogen fertilizers are used primarily for cash crops, particularly sugarcane. Whenever possible, fodder is cultivated in the pre-monsoon season. Water, however, is the input constraining agricultural production.

In 1976, a rainwater harvesting dam was built in the adjoining Sukhomajri village. In 1982, the first of Dhamala's two reservoirs was completed. The introduction of irrigation has had two important impacts, both with design implications. The first relates to the growing capacity for the local management of irrigation and forest resources. At the time of a field study in 1990, the villagers had eight years of experience with irrigation management. The second impact of irrigation, which is related to management capacity, was conflict over water. In the absence of historically defined water rights in Dhamala, influential households have sought to establish preeminence by capturing water. In 1989-90, for instance, three landed households received no water at all, a fact which resulted in major confrontation. The Forest Department's role in system management is primarily conflict resolution. To maintain a perception of equity, the department had to mediate among adversarial groups so that each received its allocated share. From an operational perspective, it was of crucial importance to control water distribution according to allocated shares in a manner which intuitively appealed to the concerned groups, until water rights were established and the supply increasingly became demand based.

The Irrigation System

An integrated watershed management program was started in Sukhomajri and Dhamala in 1976. Conservation agreements on forest use were negotiated with villagers prior to the provision of irrigation. In this sense, irrigation was used as a bargaining chip to achieve wider watershed land use planning objectives. After extensive soil and water conservation and reforestation work was implemented, earthen dams for harvesting rainwater were constructed in the hills above Dhamala in 1982 and 1983.

With catchment areas of 16.0 ha and 3.0 ha, the reservoirs have storage capacities of 6.7 ha-m and 1.3 ha-m, respectively. Supplemental irrigation was made available to potential command areas of 38 ha below the large reservoir and to 5 ha below the small one. Water flowed from the reservoirs to the commands through buried concrete pipelines. Transmission losses were high due to faulty and leaking joints in the concrete pipes. Subsequently, PVC pipes were introduced. Assuming full reservoir capacity and a conservative estimate of 10 percent combined losses, totals of only 16 cm and 23 cm of irrigation are available in the respective command areas. Because of the large potential command areas in Dhamala (the ratio of catchment to command is 1:2.3), the irrigation system is greatly water-deficient. Additionally, with the reduction in runoff due to water conservation in the catchments, water scarcity will increase.

Equal irrigation to all households regardless of landholding (*haqbandi*) was tried, but has been largely unsuccessful. It has been found that landless households are unable to trade water. Additionally, the time-based charge for water (Rs 3/hour; US$1.0 = Rs 16.70 in 1990) has not been collected, due to the perception among irrigators that the operating costs of gravity systems are low.

During the initial stages when Dhamala inherited rotational water supply based on the area of landholding from adjacent Lohgarh, maintaining a constant discharge was essential. During this period, the flume was operated according to its design objective. Over time, however, water rights became established in Dhamala with influential households with larger landholdings dominating irrigation distribution. Given the mix of income sources available to most households in Dhamala, other households turned increasingly to livestock farming and various forms of wage employment. The impact on irrigation was a gradual but definite transition to a demand-based supply. The flume was unable to meet this demand and was consequently altered.

Design of the Discharge Regulator

Detailed topographic surveys were carried out in Dhamala to determine the hydraulic extent of the command area, based on the maximum and minimum head available from the reservoir. Bounded on two sides by uphill slopes and on the third by a ravine, the command poses some topographical obstacles to open-channel distribution of irrigation. It was decided in 1983-84, when the irrigation system was constructed, that distribution would be through buried pipelines. However, it was deemed necessary to install a measuring device to be used in the mitigation of disputes over allocated distribution. Since the weir concept appealed to villagers' intuitive sense and required little extra operational effort, it was incorporated into the distribution system design. An alternative would have been to install an in-line flow meter. However, as an invisible "black box," this would have been bypassed by irrigators even more readily than the flume.

As the structure in Dhamala dates from 1983-84, a number of the design decisions taken then are not apparent now. It appears that a rational design procedure for discharge regulators and distribution structures in general should, at minimum, have the following steps:

Step 1: Ascertain the initial management capability and operating schedule. Project how these may change for future system management and operation.

Step 2: Acquire the data required for structural and hydraulic design including the diameter, slope and type of pipe both from the reservoir and to the risers, and minimum and maximum total head.

Step 3: Determine the range of hydraulic head at the structure's intake, including pipe friction and minor losses.

Step 4: Design the total height of the structure and width of the notch. The thickness of the partitioning wall must be adequate to support a man's weight (for sediment removal).

Step 5: Design the outlet in such a way that friction and outlet losses are minimized and the hydraulic head is maximized.

The construction should be done by local masons under the supervision of the irrigators to ensure the latter's satisfaction with the leveling and the dimensions of the notch. The flume in Dhamala was constructed of fired brick in cement mortar, with a rich cement-sand plaster to ensure waterproofing. Given the vertical forces exerted when the structure is in operation, an adequate foundation must be provided. This should be of random rubble masonry after sufficient wetting and compaction of the substrate. Adequate curing of the plaster is essential to prevent cracking and leakage. In Dhamala, the foundation was insufficient and curing was inadequate; hence the crack seen in Figure 7.8.1.

Operation and Maintenance

The pipe from the main reservoir leads into the bottom of the intake chamber of the flume, which has a rectangular notch weir to measure discharge (Figure 7.8.2). The valve in this inlet pipe to the flume is adjusted so that the operating head reaches the top of the weir notch. Except for the opening and closing of this pipe valve, the structure itself requires no operation.

Because sediment inflows from the reservoir are high, maintenance must be carried out on a routine basis. As the total capital cost of the structure is relatively low, major as well as minor maintenance can be performed by irrigators. However, the irrigation system in Dhamala is still viewed as state property and irrigators often do not take action until they are certain the Forest Department will not carry out maintenance.

Evaluation

In the summer of 1988, the reservoir storage dropped to a record low level. Irrigators needed to water their meager fodder crops to sustain their livestock through the drought. As the operating head in the system was insufficient to allow flow through the measuring flume, they initially tried to deepen the weir notch (Figure 7.8.1). Later, a hole was opened at the bottom of the partitioning wall. Since 1988, flow through the flume has entirely bypassed the weir, and passes directly through the hole. Because direct flow entails a lower water level in the flume, leakage through the crack in the sidewall is also minimized. The structure now meets the operational requirements of irrigators.

The flume did perform according to expectations in the short term. The long-term failure may be attributed to shortcomings in the recommended design procedure. Step 1, relating to current and future management and operation, was not given adequate consideration. The experience of adjoining Lohgarh might have indicated that irrigation would be dominated by influential households. Step 2, concerning physical design, was not addressed with the result that the concrete pipes of the distribution system had to be replaced with PVC pipes. Finally, minor losses in the system reduced the operating head below the level required for discharge through the flume, indicating that Step 3 was not followed.

Given the limited number of households with land in the command, water rights have gradually become established. Consequently, the operation of the system has shifted from a fixed-time rotational supply to a more demand-based supply. Tampering occurred during the summer season when the reservoir head was insufficient to allow discharge over the weir. Additionally, the structure cracked due to settling and leaked considerably. In essence, the discharge regulator did not have the flexibility to meet changing needs, which is the reason why irrigators have adapted it to meet their new operational requirements.

The low cost of the structure justifies its temporary use. During the six to seven year period of fixed time rotation, the distribution structure is reported to have performed well. The function of the rectangular notch weir in ensuring a perception of equity among irrigators was instrumental in mitigating disputes over water. For this reason, the flume should not be viewed as an outright failure.